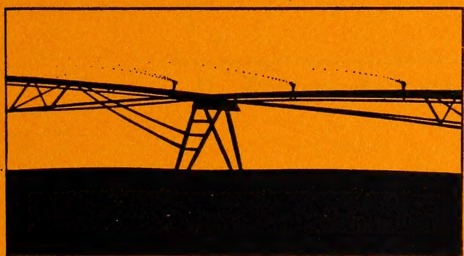
IRRIGATION AND RESOURCE MANAGEMENT DIVISION



Applied Research Report 1988-89

Alberta AGRICULTURE

PREFACE

This publication consists of reports prepared by staff involved in applied research from the Irrigation and Resource Management Division, Alberta Agriculture. Summary and progress reports on completed and ongoing research and demonstration projects for the 1988 - 1989 fiscal year are presented. The reports are limited in length for brevity. More detailed reports are available from the authors.

Reports have been grouped into one of seven sections according to the major emphasis of the subject matter. Papers are presented as they have been received from the author(s), with no attempt to modify the content. Editing and peer review have been accomplished to varying degrees for each of the reports submitted.

Also included in this report are several summary reports on research conducted by Dr. R.C. McKenzie, Research Agronomist, Alberta Special Crops and Horticultural Research Center in Brooks. These reports are of interest to those involved in irrigated and dryland agriculture in Alberta.

This publication is intended for use by people involved in agricultural extension, particularly those dealing directly with farmers.

D. Rodney Bennett, Editor

Brian Colgan, Director
Irrigation and Resource Management Division

ACKNOWLEDGEMENTS

Projects reported within this publication have been carried out with the assistance of many individuals and organizations. Gratitude is expressed to all technical, professional and administrative staff who have contributed to the planning, implementation and completion of each of these projects. Assistance from the Drafting Unit and the Soil and Water Laboratory in Lethbridge, and the Soil and Animal Nutrition Laboratory in Edmonton, are particularly appreciated.

Funding obtained for several of these projects was obtained through the Farming for the Future Program and from the Alberta Heritage Savings Trust Fund, Irrigation Rehabilitation and Expansion Research Program. This assistance is gratefully acknowledged.

A special thank you is extended to the many farmers that allowed access to their land for sampling and monitoring associated with these applied research studies.

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REVIEW OF CRACKING AND DISPLACEMENT IN REINFORCED AND UNREINFORCED LININGS

Svat Jonas[1]
Jack Stewart[2]

INTRODUCTION

Concrete lining of irrigation canals has been used extensively in southern Alberta's irrigation districts as a means of reducing seepage. The majority of concrete lining is 75 mm thick and unreinforced, constructed with a slipform. This was a popular lining method in the 1970's and resulted in approximately 295 kilometres of unreinforced concrete lined canals now in service. Unfortunately, much of the unreinforced concrete lining is severely cracked, and now does very little to reduce seepage. Several existing unreinforced concrete lined canals are now in need of major repairs or total replacement. In the past five years only reinforced concrete linings have been constructed.

The purpose of this study is to examine reinforced and unreinforced concrete linings and to observe the effects of frost penetration and water table elevation on them.

METHODS

Specially constructed frost gauges were used to monitor frost penetration and water table elevation was measured with piezometer tubes at three different depths. Cracks that appeared in the concrete lining were classified and recorded annually. Eleven of the sixteen study sites depict existing unreinforced concrete linings, three others typify existing reinforced concrete linings, and two test sites were constructed with both reinforced and unreinforced sections.

The two test sections, one in the Taber Irrigation District (TID) and the other in the Lethbridge Northern Irrigation District (LNID), were built to test various types and concentrations of reinforcing materials. The materials used included wire mesh and steel fibres.

RESULTS AND DISCUSSION

Existing Unreinforced Concrete Linings

Of the eleven sites monitored in this category two were classified as failed linings. Both canals have had sections of lining removed and replaced either with new concrete or rip rap.

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Eight of the eleven sites are categorized as having deteriorating linings. These linings are heavily cracked and are showing signs of progressive deterioration, however, they show little or no displacement of broken sections. Quite often, the cracks have been filled with polyurethane foam to stop leaks.

Of all the unreinforced concrete lined canals included in this study, only one has remained intact. Minimal cracking is evident on this lining, but no repairs have been necessary so far.

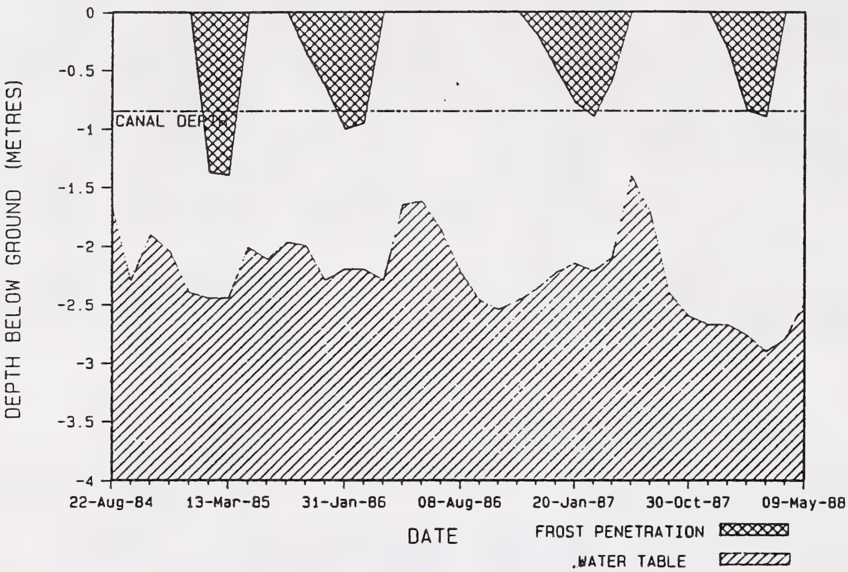

FIGURE 1. The water table extends to within 1.5 metres of the surface during the irrigation season, and this pattern has appeared fairly constant since observations began in 1984. Frost penetration has advanced to within 1 metre of the water table, but this has only occurred once. It appears that this location has a more favorable water-frost situation than others in the study and that the potential for heaving is lower than at other sites.

Existing Reinforced Concrete Linings

All three existing reinforced concrete lined canals that were monitored in this study are classified as intact linings. Frost penetration and water table graphs for these three laterals indicate conditions are similar to those encountered in the unreinforced linings in our study.

Test Sections

The results from the cracking inventory at the LNID site indicate that the section in the best condition is the unreinforced lining and the section in the poorest condition has the highest rate of reinforcing. These results are the inverse of what would be expected. In reality, the sections with the lowest rates of reinforcement have the most cracks.

The crack inventory from the TID site once again shows that the unreinforced concrete is performing better than reinforced sections. As in the LNID site, the wire mesh has the poorest crack rating, followed by the fibre reinforced concrete.

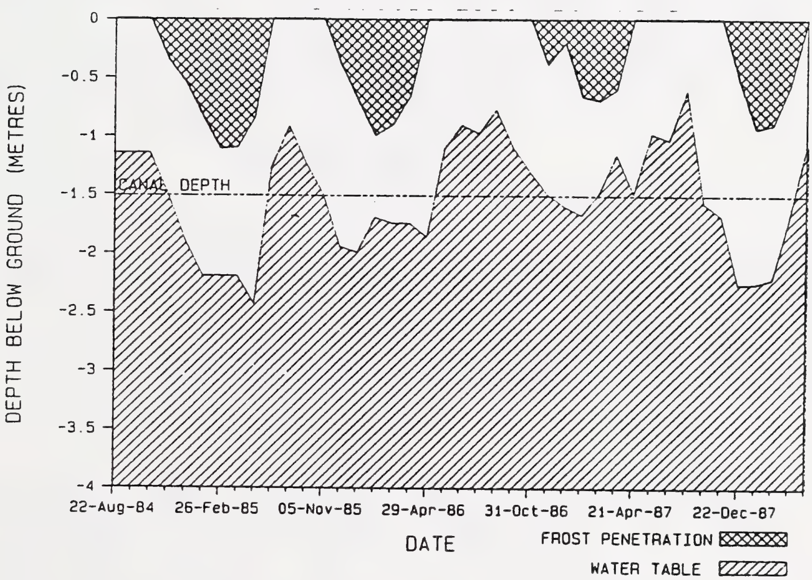

FIGURE 2. Readings since 1984 show that the water table regularly rises above the bed of this canal during the irrigation season. During the winter, frost penetration has come to within 0.75 metres of the water table on two occasions. This unreinforced concrete lining has failed because of the large amount of heaving that has occurred.

CONCLUSIONS

Although the unreinforced concrete in the test sections out performed the reinforced linings, inventories of all the reinforced linings in service in southern Alberta prove that reinforced concrete lining is durable and a much better product than unreinforced concrete lining.

Fibre reinforced concrete performs better than wire mesh in the trial sections.

The proximity of frost penetration to the water table elevation appears to have an effect on the rate of cracking and displacement.

Water table levels above the bed of the canal during the irrigation season tend to accelerate displacement and destruction of the lining.

The rate of cracking and displacement appears more dependent on water table elevations than on soil types.

It appears that concrete lining which has had cracks repaired as they appear has remained in better condition than concrete lining which has had no crack repair done.

Canals that are less than one metre deep remain in better condition than canals which are more than one metre deep.

The construction of a stable, dry, and well compacted pad is necessary to ensure support for the concrete lining.

RECOMMENDATIONS

Any new concrete lining should be reinforced, preferably with metal fibres.

Water table elevations and frost penetration should be monitored for at least two years prior to construction.

Cracks should be repaired as they appear.

A great deal of effort should be expended to ensure that a stable, properly drained and compacted pad is constructed.

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FUNCTIONAL STUDY OF IRRIGATION TURNOUT GATES PHASE II (FFF PROJECT)

Svat Jonas[1]
Jack Stewart[2]

INTRODUCTION

This irrigation turnout gate study is a follow up of an earlier study to determine the causes and extent of leakage through low head irrigation turnout gates and to identify cost effective means of reducing the leakage.

METHODS

Ten turnout gates were selected to be included in this study. Eight of them are from the previous study, the other two were recently installed and were added to investigate the leakage of a new gate.

General cleaning was carried out in early spring prior to the flow of water in the lateral. Silt and weeds around the turnout gates were removed using rakes and spades. The gates were opened and the debris and silt inside removed. The seating faces of the gates were wire brushed to remove corroded particles.

At the beginning of the experiments, leakage measurements were taken for gates in the closed position, prior to any adjustments. Flow was calculated by measuring the amount of time required to fill either a one or four litre container with water as it leaked from the gate.

After initial leakage measurements, the gates were usually operated to fully open them for flushing of weeds, debris and silt. In the course of field tests, the necessary adjustments to gate wedges and installation of various assemblies were carried out. The assemblies included; lever arms, screens, knife edges, adjustable wedges and plastic flaps. (See Figure I).

Once again leakage measurements were taken and the effectiveness of the various improvements was assessed.

RESULTS

Representative leakage rates for each gate are shown in Table I. An average of ten sets of leakage rates were taken for each gate.

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Operations of the laterals, on which the turnouts were located, was such that constant head on the gates could not be obtained. It was therefore difficult to determine in some situations whether leakage reduction was due to gate modifications or to lower head on the gate in subsequent measurements.

TABLE I
LEAKAGE RESULTS COMPARISON

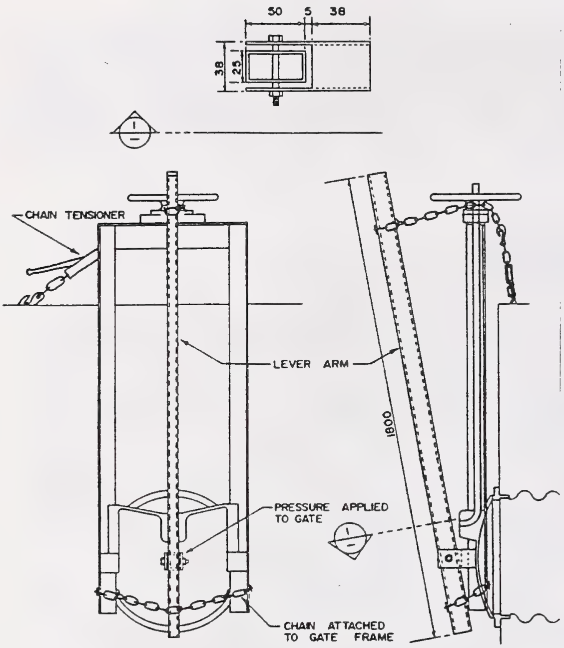
Gate	1987 Leakage (l/min)	1987 Head (cm)	1988/89 Initial Leakage (l/min)	1988/89 Final Leakage (l/min)	1988/89 Leakage Change (%)	1988/89 Head (cm)	Comments*
1	5.16	25	15.76	6.96	-56	28	SF,AW,LA,PF
2	3.90	23	52.80	2.25	-96	42	SS
3	23.70	22	5.70	171.90	+2916	20	SS,KE
4	0.78	33	2.86	0.20	-93	46	SF
5	1.44	55	4.98	4.02	-19	-	SF
6	10.50	35	78.00	33.96	-56	33	SF,AW,LA
7	62.10	74	35.70	27.66	-23	62	SF,AW
8	27.10	84	35.17	8.28	-76	82	AW
9	-	-	0.03	0.05	+67	45	NG
10	-	-	1.75	1.47	-16	45	NG

Comments:
- SF - clean seating faces
- AW - conversion of fixed wedges to ajustable wedges
- LA - installation of lever arm assembly
- PF - installation of plastic flaps
- SS - installation of screen and side boards
- KE - installation of knife edge assembly
- NG - new gate, no modifications or clean up

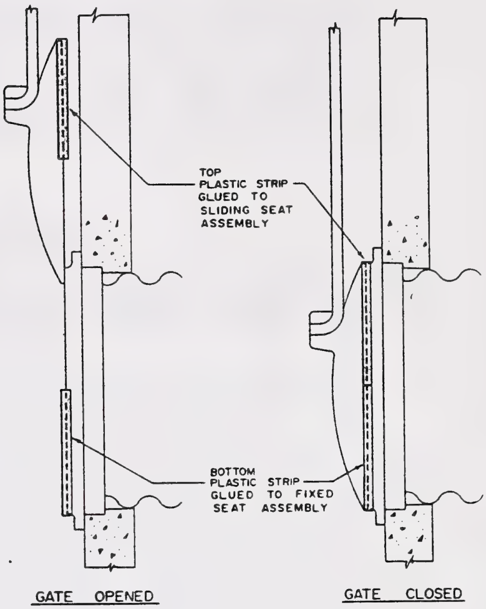
Table 1 shows that gates 3 and 9 have a negative reduction in leakage. No modifications were made on gate 9 and the increase in leakage is so low that it is insignificant. Gate 3, however, shows a drastic increase in leakage after installation of the knife edge and screen assemblies.

A reduction in leakage rates on some gates was achieved by simply keeping the gates closed for a period of time, usually between 34 and 72 hours. It appears that silt and other particulate matter in the water form a seal around the gate when it is left in the closed position for a number of days. This is true even when minimal amounts of weeds and debris are trapped in the gate.

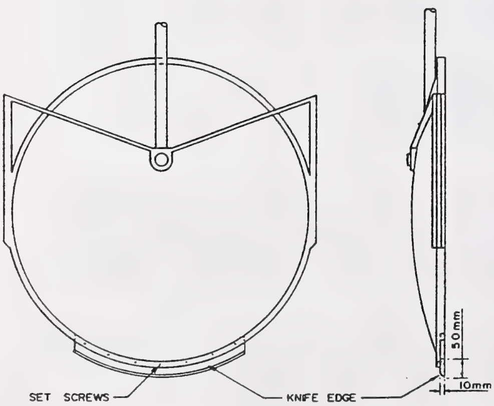
FIGURE 1



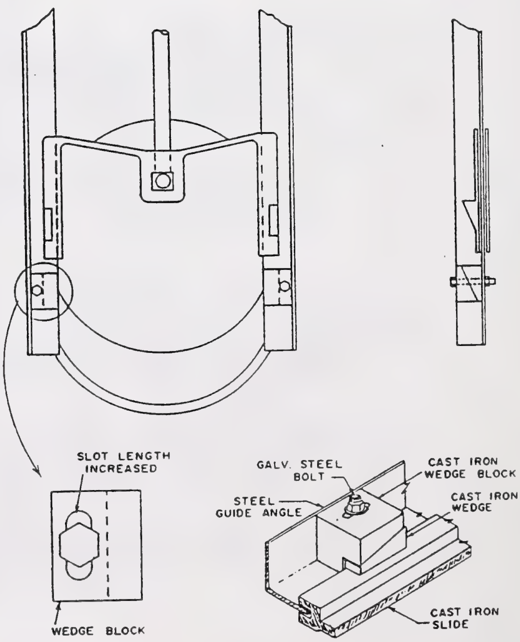
A. LEVER ARM ASSEMBLY



B. PLASTIC STRIP ASSEMBLY



C. KNIFE EDGE ASSEMBLY



D. MODIFICATION TO WEDGES

CONCLUSIONS

General maintenance by weed and silt removal, and cleaning of gate seating face contributes to leakage reduction.

The gates that have a cross bar arrangement allow pressure to be uniformly applied around the entire perimeter. Leakage rates were found to be the least in gates of this type.

Screen arrangements at the gate entrance were effective in limiting debris and weed entry into the gate. Most debris tends to collect on the upper half of the gate. Since most gates are normally not fully open, flushing of gate by fully opening it was usually effective in removing debris around the upper half of the gate.

Leakage rates on the new gates were extremely low which indicates that complete water tightness could be achieved with a gate of this type. Proper installation and initial adjustment are extremely important.

The use of the knife edge assembly to slice off weeds and debris caught in the gate during closure was not successful.

RECOMMENDATIONS

For more detailed information on leakage in turnout gates contact the authors of this report.

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IRRIGATION SUITABILITY OF SOLONETZIC SOILS
IN THE EASTERN IRRIGATION DISTRICT

D. R. Bennett[1]

INTRODUCTION

Solonetzic soils are generally considered unsuitable for irrigation development due to the undesirable characteristics of the solonetzic B horizon, high levels of subsoil salts and extreme variability of soils with Solonetzic landscapes. Increased demand for expanded development in areas of Solonetzic soils in the Eastern Irrigation District (EID) using sprinkler irrigation methods, and apparently successful development of some of these soils in the short term, prompted Irrigation Council to commission further research on this subject. A study was initiated in 1983 with the objective of assessing changes in soil quality and productivity in irrigated Solonetzic soils over a five-year period and evaluating the adequacy of existing land classification standards for irrigation.

METHODS

The study was conducted in four phases from 1983 to 1988 by private consultants under contracts funded through Irrigation Council from the Alberta Heritage Savings Trust Fund, Irrigation Rehabilitation and Expansion Research Program. Phase I (Site Selection), Phase II (Site Characterization) and two years of Phase III (Annual Monitoring) were performed by Western Soils Consulting Ltd. The final three years of annual monitoring and Phase IV (Final Evaluation) were conducted by Lakeside Research and NORMAC A.E.S. Ltd. (Lakeside Research and NORMAC A.E.S. Ltd. 1989).

A total of nine Solonetzic soil associations, irrigated by eight sprinkler irrigation systems, were chosen for the study (Fig. 1) and at least three plots were established within each site. Monitoring activities included regular measurements of soil moisture content, water-table levels and

Figure 1. Location plan.

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irrigation and precipitation amounts. Crop and soil sampling were also conducted on an annual basis. No attempt was made to influence management practises used by the farmers involved in the study.

RESULTS AND DISCUSSION

Solonetzic Characteristics

All nine soil associations examined in this study were characterized in 1983 as having more than 30 percent Solonetzic soils within the landscape. Land units represented by the selected plots at each of the sites would clearly be considered nonirrigable according the existing land classification standards for irrigation (Alberta Agriculture 1983).

Most of the Solonetzic Order soils at each of the sites were described as Brown Solods, except at the Eastman site where Brown Solodized Solonetz soils were the dominant subgroup. This observation is significant because Solods represent the most highly degraded and mildest group of Solonetzic soils. Chemical characteristics of the Solonetzic and Chernozemic soils sampled within each of the sites indicate that the A and B horizons are characterized by moderate salinity and sodicity. High salinity and sodicity levels (ECe greater than 6 dS/m or SAR greater than 12) in the parent geological material, C1 and C2 horizons, that was generally encountered at 0.3 - 0.5 m depths, inevitably resulted in a nonirrigable rating for most of the profiles examined. Extreme variability in morphological and chemical characteristics within each site was also noted during the characterization phase of the study.

Water-Table Levels

Permanent water tables within less than 1 m were not detected at any of the monitoring sites during the five-year study. Temporary responses were observed on at least one plot at each site as a result of irrigation and major precipitation events and surface ponding in depressional areas. A permanent high water table at about 2 m at the Walde site may be caused by seepage from the relocated canal that bounds the established plots on two sides. High water-table levels at the Burrows (2-3 m) and Parker (3-4 m) sites may merit further monitoring if irrigation is allowed to continue at these sites. Application of irrigation water has apparently had little impact in raising water-table levels to critically shallow depths at all of the sites irrigated with centre pivots.

Moisture Movement and Storage

The observation by Lakeside Research and NORMAC A.E.S. Ltd., wherein variation in soil moisture content was most pronounced within the upper 0.6 m depth, is consistent with other southern Alberta studies related to moisture redistribution under centre pivots. Pohjakas (1983) observed similar variation in near-surface moisture content as a result of centre pivot irrigation, precipitation events and crop water use. Downward movement of water below the B horizon was apparent on most of the plots, however, changes in moisture content within the lower root zone were less evident.

Changes in Soil Chemical Parameters

Extreme variation in soil chemical parameters within the soil profiles at each site made it very difficult to detect significant differences in these parameters over time. Extremely large differences in these values over time would be required to obtain a statistically significantly difference. Irrigation management observed over the five-year period was not conducive to extensive leaching of salts. Increased production associated with irrigated agriculture resulted in a statistically significant increase in pH for the A and B horizons at all of the sites. Other significant trends in soil chemical parameters were not readily apparent, except for increased sodicity in the subsoil at the Walde and Henrickson sites, suggesting that the salt status of soils at most of the sites has remained about the same over the five-year period.

Moisture Use and Crop Yield

Irrigation and crop management practises apparently played a major role in relation to crop yield levels observed at each of the sites over the five-year monitoring period. Factors that may have contributed to a poor correlation between water use and crop yield include the timeliness of irrigation events, soil fertility deficiencies, inadequate weed control and a number of climate, equipment or pest-related problems.

Comparison of yield data for each of the seven crops grown at the nine study sites to unpublished data collected by Irrigation Branch and to attainable, expected and lower yield relationships adapted from Underwood McLellan Ltd. (1982), indicate that good yields were attained on some plots (Fig. 2). Soil limitations associated with the Solonetzic character of these soils associations, and some of the irrigation and crop management factors identified above, may account for the relatively poor yields obtained on most of the plots most of the time.

Irrigation Suitability of Each Study Site

Five of the nine sites were considered suitable for continued irrigation by the consultants - Drotos Lacustrine, Drotos Till, Eastman, Leemhuis and Tajiri. The other four sites were found to have limitations that warranted further study - Burrows, Henrickson, Parker and Walde. Productivity of most of the sites over the five-year period appears to be well below a viable level, even though deterioration of soils was generally not detected.

RECOMMENDATIONS

The following recommendations were made by Lakeside Research and NORMAC A.E.S. Ltd. (1989):

(1) The yields obtained under irrigation of Solonetzic soils appeared to be moderate to good under good management. An economic feasibility study should be considered to assess the cost-benefit of developing such soils.

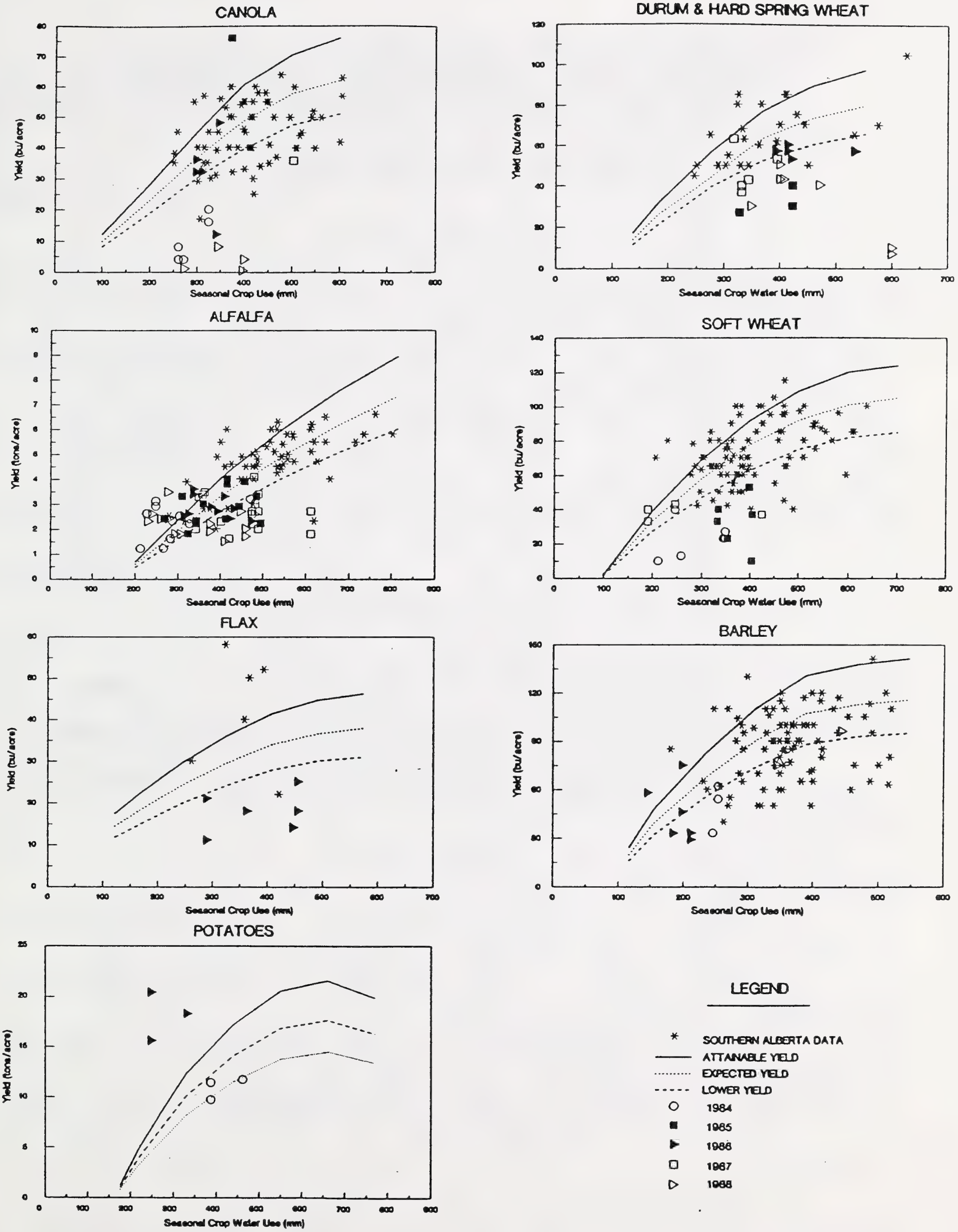

Fig. 2. Comparison of crop yields obtained on the nine monitoring sites to southern Alberta data.

(2) No deleterious effects were noted on most of the soils. In fact, slight improvements were noticeable at most of the sites. The exceptions were the Henrickson site, where subsoil salts showed an increase (not statistically significant) and the Walde site, where the water table increased to around 2 m.
(3) Permanent water table installations should be made at the sites and water table monitoring continued on a monthly basis over the next five years.
(4) In five years (1993), the feasibility of continued irrigation at the Henrickson, Walde, Parker and Burrows sites should be re-evaluated. The evaluation should concentrate on sustained economic productivity.
(5) In five years (1993), the sites from this study should be relocated and sampled as they were in 1988. The changes in chemical parameters should be re-evaluated at that time.
(6) The present Alberta irrigation classification system appears to require revision to allow the irrigation of suitable Solonetzic soils. The following modifications are recommended for consideration:
    (a) The criterion of a maximum SAR of 12 is too restrictive, especially since there does not appear to be good justification for this limit.
    (b) The current system lacks an integrated approach that combines soils information with topographic, subsurface groundwater drainage, and long-term productivity information.
    (c) The texture criteria should be grouped into fewer categories for sprinkler irrigation.
    (d) Consideration should be given to merging the textural and geological criteria.
    (e) The profile element of the BSR for Solonetzic soils appears to be relatively low compared to Chernozemic soils but revision is not recommended without further study. A diagnostic rating of the roughness of the Bnt would be preferred.

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ASSESSMENT OF THE ECONOMIC VIABILITY OF CONTINUED IRRIGATION OF NINE SOLONETZIC SOIL ASSOCIATIONS IN THE EASTERN IRRIGATION DISTRICT

L.J. Klusa[1] and D.R. Bennett[2]

INTRODUCTION

This article summarizes the findings of the study "Assessment of the Economic Viability of Continued Irrigation of Nine Solonetzic Soil Associations in the Eastern Irrigation District" completed by Jim Lore & Associates Ltd. for Alberta Agriculture. D.R. Bennett, the Project Manager, coordinated the study and provided background information.

The purpose of this study was to provide economic data and recommendations to be used for verification or modification of existing land classification standards for irrigation. The objectives of the study were to estimate costs and returns of production for seven agricultural crops and to evaluate crop yield and irrigation management data from a five-year period on nine Solonetzic soil associations in the Eastern Irrigation District.

METHODS

The data provided from the five-year study "Irrigation of Solonetzic Soils" (Lakeside Research and NORMAC A.E.S. Ltd. 1989) were examined in two stages. The first stage was the analysis of individual crop data from all of the study sites. The second stage was the analysis of individual site data.

In stage one, individual crop data were analyzed as follows:

(1) Data on yield, irrigation levels, precipitation, and total moisture received for each crop were summarized. The relationship between individual crop yield and moisture received was examined by plotting yield and moisture data, running a regression analysis on the individual points, and using grouped data for various moisture levels.

(2) Individual crop yield data from the study were compared to historical crop yield data.

(3) A production model was developed to estimate costs and returns for each crop. The model estimated costs and returns of production and returns based on current input costs, historical irrigation yields and historical crop prices. Gross operating profit was calculated for each crop and compared to the gross operating profit of historical crop yields. The costs of irrigation were estimated for

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each level of irrigation, as well as the potential returns. A break-even price and yield were calculated for study yields and prices.

In stage two, individual site data were analyzed as follows:

(1) Individual site yields were compared to historical crop yields.

(2) Individual site gross operating profits were compared. The risk of returns was examined, based on the standard deviation of returns.

RESULTS AND DISCUSSION

Analysis of Study Data

The yield data were highly variable (Table 1) and the relationship between yield and total moisture received was poor. This is not what would be expected. Crops on Solonetzic soils apparently do not withstand drought periods as well as crops on other soils.

Table 1. Crop yield summary

	CROP YIELD				
Crop	Mean	Standard Deviation	Minimum	Maximum	Number of plots
Alfalfa (tons/acre)	2.53	0.691	1.2	4.0	65
Barley (bu./acre)	57.5	24.04	29.0	96.0	12
Canola (bu./acre)	21.1	20.95	0.4	76.0	16
Flax (bu./acre)	17.8	4.95	11.0	25.0	6
Hard Wheat (bu./acre)	42.9	15.42	7.0	63.0	21
Potatoes (tons/acre)	14.6	4.27	9.8	20.5	6
Soft Wheat (bu./acre)	31.8	12.76	10.0	53.0	19

The only crop which out-performed historical yields was potatoes (Table 2). Alfalfa, barley, canola, flax, hard wheat, and soft wheat fell below historical crop yield averages. The mean yields of seventeen of the twenty-one crops grown on the nine study sites were below historical crop yield averages.

Table 2. Study yield versus historical yield

Crop	Historical Crop Yields	Study Yields	Percentage Difference
Alfalfa	4.91 tons/acre[1]	2.53 tons/acre	-48.5%
Barley	67.3 bu/acre[2]	57.5 bu/acre	-14.6%
Canola	31.2 bu/acre[2]	21.1 bu/acre	-32.4%
Flax	26.2 bu/acre[2]	17.8 bu/acre	-32.1%
Hard Wheat	44.3 bu/acre[2]	42.9 bu/acre	- 3.2%
Potatoes	10.01 tons/acre[2]	14.6 tons/acre	45.9%
Soft Wheat	68.0 bu/acre[2]	31.8 bu/acre	-53.2%

Sources:

[1] Alberta Agriculture. 1989. Alfalfa yields under irrigation collected in the Lethbridge Area, 40 data years. Agdex 120-32.

[2] Alberta Hail and Crop Insurance Corporation. 1979. Ten Year Average for Crops Grown Under Irrigation, Risk Area 3.

Estimation of Costs and Returns

Only alfalfa and potato yields resulted in a positive average gross operating profit per acre, based on the cost and return model developed in the study (Table 3). Establishment costs for alfalfa were ignored in

Table 3. Gross operating profit by crop

Crop	Mean Gross Returns Per Acre ($/Acre)	Mean Direct & Indirect Costs ($/Acre)	GROSS OPERATING PROFIT ($/ACRE) Max	Min	Stdev	Mean
Alfalfa ($70.00/ton)	177.05	170.44	109.72	-80.73	47.85	6.61
Barley ($2.25/bu)	129.38	190.19	19.72	-122.50	51.54	-60.82
Canola ($6.00/bu)	126.53	177.57	275.33	-181.67	124.96	-51.05
Flax ($7.00/bu)	124.83	186.63	-11.22	-107.61	34.79	-61.79
Hard Wheat ($4.25/bu)	182.14	189.43	81.00	-172.74	69.26	-7.29
Potatoes ($90.00/ton)	315.50	1,212.46	653.74	-336.52	399.51	103.04
Soft Wheat ($3.50/bu)	111.45	191.39	-9.38	-157.97	44.25	-79.95
All Crops	204.62	222.14	653.74	-336.52	105.37	-17.53

the gross operating profit analysis. Thus gross operating profit may be overestimated in the study model.

Only four of the nine Solonetzic soil sites had a positive gross operating profit based on the cost and return model in the study (Table 4). Gross operating profit was low or negative for all of the study

Table 4. Gross operating profit by site

Site	Mean Gross Returns Per Acre ($/Acre)	Mean Direct & Indirect Costs ($/Acre)	GROSS OPERATING PROFIT ($/ACRE) Max	Min	Stdev	Mean
Burrows	165.20	169.42	32.30	-48.89	26.27	-4.22
Drotos Lac.	114.52	177.98	13.01	-122.50	36.53	-63.46
Drotos Till	114.45	178.05	4.44	-147.96	50.69	-63.60
Eastman	179.73	184.10	275.33	-155.05	105.50	-4.37
Henrickson	215.96	184.33	105.96	-30.51	39.80	31.63
Leemhuis	103.95	185.41	37.66	-181.67	65.91	-81.46
Parker	183.40	168.90	109.72	-80.73	60.42	14.50
Tajiri	613.18	598.07	653.74	-336.52	258.17	15.12
Walde	180.93	177.88	85.66	-117.61	56.82	3.05
All Sites	204.62	222.14	653.74	-336.52	105.37	-17.53

sites. The sites producing the highest gross operating profit and the higher yields were the Henrickson and Tajiri sites. Gross operating profit was high at the Tajiri site because potatoes were grown on the site two out of the five years. The potato yields were above historical levels. Gross operating profit was high at the Henrickson site because hard wheat out-yielded historical crop yields and alfalfa yields were higher than at other study sites. The two other sites that produced a positive gross operating profit were the Parker and Walde sites.

Alfalfa was grown on these two sites which helped to increase the gross operating profit. The yield of alfalfa on these two sites was well below historical alfalfa crop yields. The gross operating profit for individual crops and sites was very sensitive to changes in crop prices.

Break-even Analysis

The break-even point for this study was calculated as gross revenue equal to the sum of direct and indirect costs. Assuming that costs are fixed,the break-even point would depend on the amount of crop produced or the price received for the crop.

Break-even yield requirements, using the crop prices and the cost model from the study are presented in Table. 5.

Table 5. Break-even yield

Crop	Price ($)	Break-even Yield
Alfalfa	70.00/ton	2.40 tons/acre
Barley	2.25/bu.	86.1 bu/acre
Canola	6.00/bu	29.4 bu/acre
Flax	7.00/bu.	27.2 bu/acre
Hard Wheat	4.25/bu.	44.9 bu/acre
Potatoes	90.00/ton	13.3 tons/acre
Soft Wheat	3.50/bu.	54.9 bu/acre

Table 5 indicates that study yields for soft wheat, barley, canola and flax would have to increase considerably for gross operating profit to equal zero, based on the study prices.

Break-even price requirements for each crop, using study yields and the cost model from the study are outlined in Table 6.

Table 6. Break-even price

Crop	Study Yields	Break-even Price
Alfalfa	2.53 tons/acre	$66.40/ton
Barley	57.5 bu/acre	3.37/bu.
Canola	21.1 bu/acre	8.51/bu.
Flax	17.8 bu/acre	10.71/bu.
Hard Wheat	42.9 bu/acre	4.45/bu.
Potatoes	14.6 tons/acre	82.22/ton
Soft Wheat	31.8 bu/acre	6.05/bu.

CONCLUSIONS

Conclusions drawn from the analysis of the study data are as follows:

(1) Production of a variety of irrigated crops on the Solonetzic soils monitored in the Eastern Irrigation District is not economically viable because of low yield performance, extreme variability of yield and insufficient gross operating profit. The risk associated with crop production under irrigation on Solonetzic soils is increased because of lower productivity of the soils and the extreme variation in yield.

(2) The low yields and extreme variability of returns would indicate that continued irrigation of the Burrows, Drotos Lacustrine, Drotos Till, Eastman, Leemhuis, Parker and Walde sites is not advisable. A recommendation for continued or discontinued irrigation on the Henrickson and Tajiri sites cannot be made based on the data in the study. Further study of the Henrickson and Tajiri sites, to verify consistency of high crop yields, should be considered. The high yield of potatoes on the plots at the Tajiri site is encouraging and further study of the production of potatoes on similar Solonetzic soils should be considered.

(3) The costs of production, using an irrigation management system, are high. In order to meet these higher costs, a consistently high level of crop yield is required. Low yields under irrigation will result in larger losses to an irrigation farmer than to a dry-land farmer, because of the higher level of capital and input costs required.

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EVALUATION OF SALINITY STANDARDS FOR LAND CLASSIFICATION USING IRRIGATED LYSIMETERS

D.R. Bennett, T.M. Peters and P.D. Lund[1]

INTRODUCTION

The objective of this study was to determine the effects of the depth to moderately fine-textured, saline-sodic subsoil on movement of salt within the soil profile and on crop growth under irrigation. Existing land classification standards for irrigation (Alberta Agriculture 1983) specify that the electrical conductivity of the saturation paste extract (ECe) must be less than 6 dS m^{-1} within the upper 0.5 m and less than 12 dS m^{-1} within the remainder of the 1 m root zone for an irrigable rating to be assigned. Soil sodicity, as denoted by the sodium adsorption ratio (SAR), must also be less than 12 within the upper 1 m profile. These criteria are used to evaluate soils being considered for irrigation development as well as for reclassification of soils that are undergoing reclamation.

MATERIALS AND METHODS

Thirty-six lysimeters with dimensions of 1.5 m long by 38 cm (ID) were constructed from polyvinylchloride (PVC) pipe and were placed in the field within an excavated pit. The top of each lysimeter was situated at a level similar to the adjacent ground surface. Treatments consisted of various combinations of moderately fine-textured, nonsaline (ECe 2 dS m^{-1}) lacustrine soil and saline-sodic glacial till subsoil of similar texture added to each lysimeter (Fig. 1). Two types of saline-

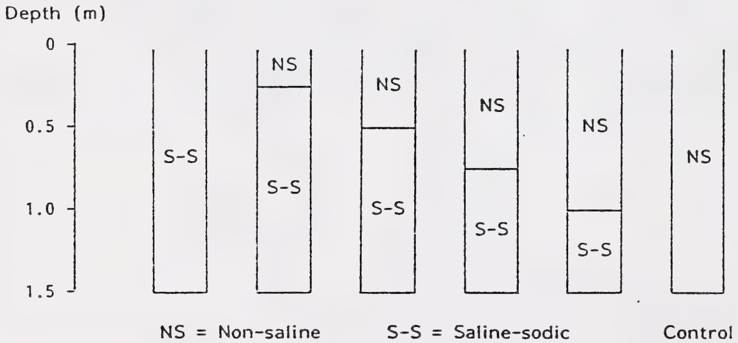

Figure 1. Treatments used to evaluate the effects of the depth to saline-sodic subsoil.

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[1] Land Evaluation Section, Land Evaluation and Reclamation Branch, Alberta Agriculture.

sodic subsoil material were used for the study: saline-sodic material from a recently salinized soil in the Raymond Irrigation District (SLN treatment); and saline-sodic material from a Solonetzic soil association in the Bow River Irrigation District (SZ treatment). Numbers following each treatment designation indicate the depth of nonsaline material present within each lysimeter. Replicates were established in triplicate and were placed randomly within the pit.

Lysimeters were prepared by placing 50 mm of fine gravel on the bottom and then by adding soil that had been passed through a 4 mm screen. Soil was added to lysimeters in increments of 0.40 m to a depth of 1 m and in increments of 0.25 m to within 50 mm of the top of each lysimeter. The soil was compacted to a bulk density of 1.4 within each interval. Three samples of soil, added to each depth interval, were bulked for analytical determination of the initial soil chemistry. Laboratory analyses included pH, ECe, soluble cations and anions and SAR. Stabilization of soil in the lysimeters was promoted by adding 100 mm of irrigation water to the lysimeters in the fall of 1987.

Instrumentation used in conjunction with the lysimeters included a spigot and tubing installed at the bottom of each lysimeter to permit detection of the existence of a water table and to allow drainage and collection of effluent. A tensiometer was installed at a depth of 0.5 m in each lysimeter and a rain gauge was installed at the site to measure natural precipitation. Three salinity sensors were installed within each lysimeter at depths of 0.3, 0.6 and 0.9 m below the soil surface.

Lysimeters were prepared for cropping in 1988 by mixing fertilizer into the upper 0.15 m of soil. Nitrogen and phosphorus (P_2O_5) were added at a rate of 70 and 30 kg ha^{-1}, respectively. Galt barley was seeded to each lysimeter using a template that allowed planting of 40 seeds per lysimeter. Seedlings were thinned to 30 per lysimeter in three weeks following the date of seeding. A total of 50 mm was applied in 10 mm increments in the spring of 1988 to promote germination in the absence of natural precipitation. Only 10 mm were added in the spring of 1989 because adequate rainfall was received.

Irrigation water was then added to each lysimeter in increments of 100 mm when the tension exceeded 59 kPa in a minimum of two of the three replicates. Lysimeters were drained whenever the presence of a water table was evident in the tubing. The volume of drainage water collected from each lysimeter was measured and effluent was analyzed for pH, EC, soluble cations and anions and SAR. Similar water quality analyses were performed on irrigation water used in the experiments.

Lysimeters were cropped during the 1988 and 1989 growing seasons, after which soils were sampled in the fall of 1989 at the same depths that were used initially. Barley yield was determined by counting the number of heads and by measuring total dry matter and grain weights for each lysimeter. Soil samples were analyzed in the laboratory for the same soil chemical parameters utilized for initial characterization.

PRELIMINARY RESULTS AND DISCUSSION

Initial Soil Salinity and Sodicity Levels

ECe values within the saline-sodic subsoil material ranged from 18 to 23 dS m^{-1} and SAR values were within the 30 to 35 range (Fig. 2).

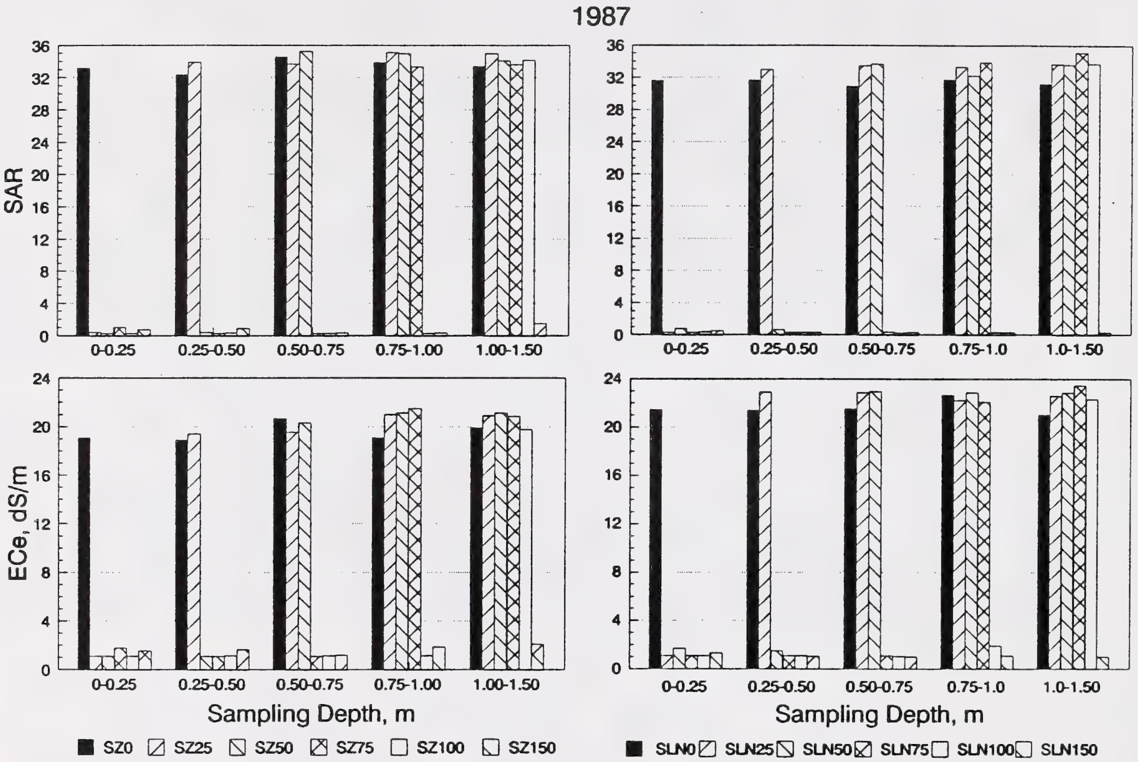

Figure 2. Mean salinity and sodicity levels of soil added to lysimeters for each of the treatments.

These levels of salinity and sodicity would result in nonirrigable ratings for all treatments having less than 1 m of nonsaline material above the saline-sodic subsoil.

Excessive salinity levels within the root zone affect the productive capability of irrigated soils because of the shallow root development that is characteristic of crop growth in saline soils and due to the potential for upward migration of soluble salts between irrigation events and during the fall and winter seasons. High sodicity levels within the subsoil usually reflect an abundance of relatively soluble sodium salts that may migrate upward in response to a moisture gradient.

Barley Yield

Statistical analyses of mean yield data for each treatment in 1988 and 1989 (Fig. 3) indicate that at least 50 cm of nonsaline material was required for adequate production of barley. Yield obtained in 1988 for 50 and 75 cm depths of nonsaline material was similar to or significantly

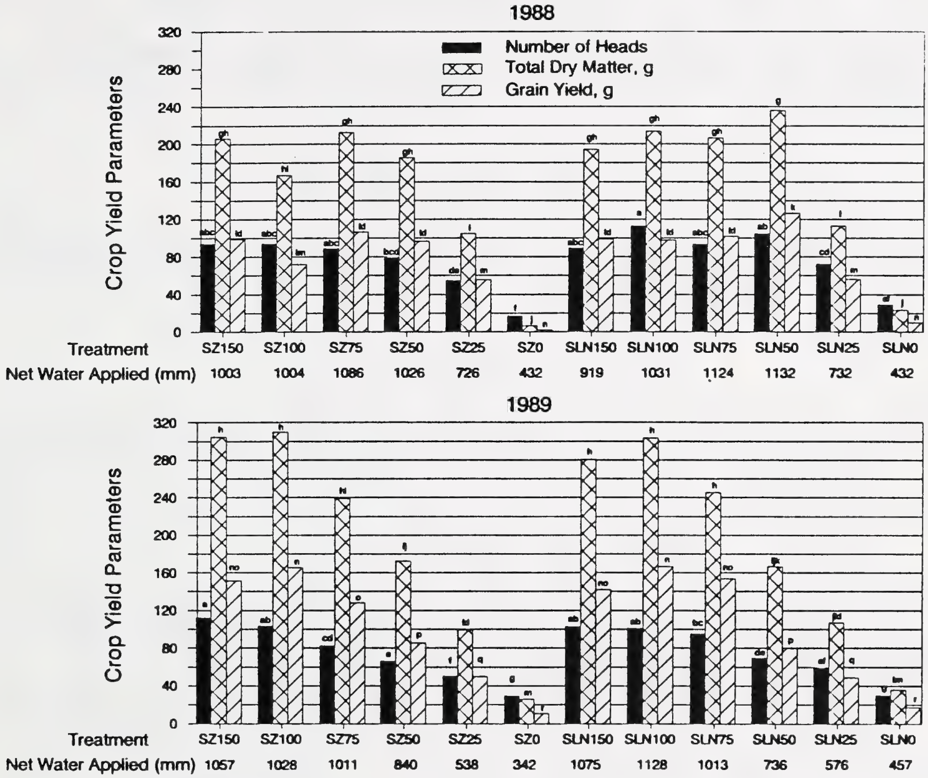

Figure 3. Mean barley yield obtained for each treatment in 1988 and 1989.

greater than most yield parameters from 100 and 150 cm treatments. However, considerably greater quantities of water were applied to achieve the same levels of production. Barley yield in 1989 was also influenced by the amount of water applied, with significantly higher yield observed in treatments having at least 75 cm of nonsaline material.

Root distribution and soil moisture conditions observed during final soil sampling activities in 1989 indicated that root development was restricted almost exclusively to the nonsaline material and the entire depth of saline-sodic subsoil was moist to very moist, as compared to the relatively dry nonsaline material from which moisture had been used by the crop.

The main effect of excess salinity on plants is suppression of growth resulting from increased osmotic stress (Hoffman et al. 1983). Crops differ significantly in their ability to tolerate excessive levels of salinity, with linear yield reductions usually evidenced once a threshold salinity level is exceeded (Maas and Hoffman 1977). Plants generally respond to a weighted-mean salinity, based upon differential uptake of water with depth in the root zone, wherein the effective salinity level must be weighted in favor of the least saline zone (Bernstein and Francois 1973). Other studies suggest that plants respond to the mean salinity of the entire root zone (Shalhevet and Bernstein 1968; Bower et al. 1969).

ACKNOWLEDGEMENTS

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COLUMN LEACHING STUDY ON BROWN SOLONETZIC SOILS

D.R. Bennett and P.D. Lund[1]

INTRODUCTION

Soils of the Solonetzic Order in the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987) are presently rated nonirrigable under existing land classification standards (Alberta Agriculture 1983). Previous research on irrigation of Solonetzic soils has been rather inconclusive, indicating a need to determine specific soil or water management characteristics that contribute to successful irrigation or deterioration of these soils. Recent findings suggest that the soil chemical criteria presently used to define a solonetzic B horizon taxonomically are somewhat inadequate for irrigation suitability classification (Bennett 1988).

The objective of this project was to determine the effect of irrigation on the salinity and exchangeable-sodium status of Brown Solonetzic soils in southern Alberta. Implications of this research on standards for evaluation of the irrigation suitability of Solonetzic soils and differentiation of soils in the Canadian System of Soil Classification were also addressed.

MATERIALS AND METHODS

Site Selection and Sampling

Selection of sampling sites was based on existing Level II and III land classification information and available soil survey maps. Brown Solonetzic soils from the Eastern Irrigation District (E.I.D.) and Bow River Irrigation District (B.R.I.D.) were selected for sampling. Soils at each sampling site were cored to a depth of at least 1.5 m to permit detailed characterization of the soil profile and underlying parent material. Profiles were described according to the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987). Three similar investigation sites at each location were chosen for pit excavation and detailed soil sampling. Samples were gathered from the A and Bnt horizons and from the C horizon above 0.5 m and from 0.5 to 1 m. Seven soil types were sampled in this manner from five locations in E.I.D. and two locations in B.R.I.D.

Column Leaching Tests

Soil columns for leaching were prepared by packing 250 g of less than 2 mm diameter B horizon soil into 5-cm OD (4.4-cm ID) plastic cylinders to a bulk density of 1.4 g cm^{-3}, a soil column 11.75-cm in length. Three columns were prepared from each B horizon sample

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(triplicate samples) for leaching under subsaturated conditions. Tests were conducted simultaneously on 18 columns. Subsaturated columns were leached by applying irrigation water in 1 cm (15.3 mL) increments, at a maximum rate of 1 cm d^{-1}. Irrigation water having an EC within the 0.3 to 0.5 dS m^{-1} range was used for all leaching tests.

Drainage water was monitored for EC and the composition of major cations and anions. The volume of drainage water was expressed in pore volume units to scale out differences in the moisture retention characteristics of the different soils and to compensate for wetted pore space differences between the ponded and subsaturated treatments (Jury et al. 1979). A pore volume in a soil having a bulk density of 1.4 represents a volume of approximately 84 mL of leachate from these columns. The volume of leachate, up to but not exceeding poor volume increments, was bulked for subsequent laboratory analyses on a pore volume basis. An attempt was made to leach five pore volumes of irrigation water through each of the columns. Irrigation was discontinued on columns that did not permit infiltration of irrigation water after three days of ponding.

PRELIMINARY RESULTS

Soil Characteristics

Soils investigated at the seven study sites represent a wide range of Brown Solonetzic soils (Table 1). All of the profiles investigated

Table 1. Taxonomic classification of soils used for the column leaching tests

Site	Hole Number	Profile Description	Depth of B Horizon (m)	Parent Material	ExCa:ExNa of B Horizon	Soil Series
NW 30-12-15-W4	1	B.SS	0.06 - 0.26	Till	6.06	Hemaruka
	2	B.SS	0.07 - 0.13	Lac	3.56	Wardlow
	6	B.SS	0.05 - 0.10	Till	4.45	Hemaruka
NW 04-13-16-W4	7	B.SS	0.08 - 0.33	Till	2.24	Hemaruka
	8	B.SS	0.07 - 0.28	Till	1.45	Hemaruka
	9	SZ.B	0.15 - 0.31	Till	14.64	Cecil
SW-14-16-13-W4	13	B.SS	0.18 - 0.37	Lac/Till	2.37	Duchess
	15	B.SS	0.36 - 0.56	Eol/Lac	1.15	Rolling Hills
	17	B.SS	0.54 - 0.90	Eol/Lac	3.96	Rolling Hills
NW 33-16-12-W4	21	B.SS	0 - 0.10	Lac	5.44	Patricia
	22	B.SS	0 - 0.18	Lac	4.67	Patricia
	23	B.SS	0 - 0.15	Lac	6.95	Patricia
NE 05-18-12-W4	25	B.SS	0.11 - 0.25	Till	5.66	Hemaruka
	28	B.SS	0.04 - 0.11	Till	8.53	Hemaruka
	29	B.SS	0.07 - 0.17	Till	5.93	Hemaruka
SE 36-19-13-W4	33	B.SS	0 - 0.15	Till	1.63	Hemaruka
	35	B.SS	0.03 - 0.15	Till	2.17	Hemaruka
	36	B.SS	0.03 - 0.30	Till	5.17	Hemaruka
NW 27-21-16-W4	38	B.SS	0.1 - 0.25	Till	3.82	Hemaruka
	39	B.SS	0.05 - 0.25	Till	5.80	Hemaruka
	42	B.SO	0.35 - 0.55	Lac/Till	3.52	Gem

consisted of Brown Solodized Solonetz soils, except for one Solonetzic Chernozemic soil and one Brown Solod. Exchangeable calcium to sodium ratios varied from 1.15 to 14.64. Some of the chemical and physical characteristics of the soil profiles are also presented (Table 2). Soil pH ranged from 6.0 to 8.0, ECe varied from 0.33 to 3.19 dS m^{-1}, SAR ranged from 3.25 to 16.47 and CEC values were 7.98 to 44.11 cmol(+) kg^{-1}. Clay content in these soils ranged from 14 to 54 percent.

Table 2. Chemical and physical characteristics of soils at the seven study sites

Site	Hole Number	pH	ECe dS m^{-1}	SAR	CEC cmol(+)kg^{-1}	Exchangeable Cations cmol(+)kg^{-1} Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Particle-Size Distribution,% Wgt S	Si	C
NW 30-12-15-W4	1	8.0	0.77	10.61	44.11	29.47	9.21	4.86	0.57	23	26	51
	2	7.7	2.76	13.45	26.55	11.47	10.70	3.22	1.16	37	31	32
	6	7.9	1.01	11.78	36.39	20.89	10.24	4.69	0.57	33	24	43
NW 04-13-16-W4	7	6.8	3.19	16.47	19.64	7.70	7.02	3.43	1.49	31	29	40
	8	6.8	1.90	13.68	18.88	4.97	8.62	4.03	1.26	34	27	39
	9	6.0	0.33	3.25	16.77	9.37	5.59	0.64	1.17	22	43	35
SW 14-16-13-W4	13	6.7	0.71	8.06	21.63	6.87	10.57	2.90	1.29	27	35	38
	15	7.4	0.78	9.19	13.86	3.12	6.84	2.71	1.19	38	36	26
	17	7.0	0.49	7.80	12.36	5.38	4.60	1.36	1.02	42	36	22
NW 33-16-12-W4	21	6.9	0.53	4.85	24.65	10.88	10.28	2.00	1.49	12	34	54
	22	7.0	0.56	6.51	23.77	10.51	9.44	2.25	1.57	14	38	48
	23	7.1	0.58	5.31	22.80	10.49	9.43	1.51	1.37	15	37	48
NE 05-18-12-W4	25	7.0	0.53	4.97	27.11	11.21	12.45	1.98	1.47	24	27	49
	28	7.5	0.66	5.30	33.48	15.70	14.15	1.84	1.79	21	27	52
	29	7.5	0.74	6.40	31.28	14.77	12.58	2.49	1.44	22	24	54
SE 36-19-13-W4	33	6.9	1.49	9.55	21.55	4.67	12.66	2.86	1.36	24	33	43
	35	7.7	1.49	9.63	18.25	6.99	6.63	3.22	1.41	33	35	32
	36	6.6	0.61	7.50	28.14	17.72	5.97	3.43	1.02	27	23	50
NW 27-21-16-W4	38	6.8	0.69	8.34	19.29	9.51	6.69	2.49	0.60	58	12	30
	39	6.0	0.40	6.20	17.17	7.94	7.04	1.37	0.82	48	14	38
	42	7.1	0.63	10.40	7.98	3.94	2.30	1.12	0.62	64	22	14

Soil Chemical Changes

Five pore volumes of water were not successfully leached through all three replicates of 16 of the 21 soils examined in this study due to restricted infiltration over a prolonged period. Eleven of the unsuccessful tests were terminated prior to collection of even one pore volume of leachate.

Comparison of soil salinity and sodicity values at the conclusion of leaching to levels prior to commencement of the tests (Fig. 1) indicate that substantial reductions in ECe and/or SAR were achieved

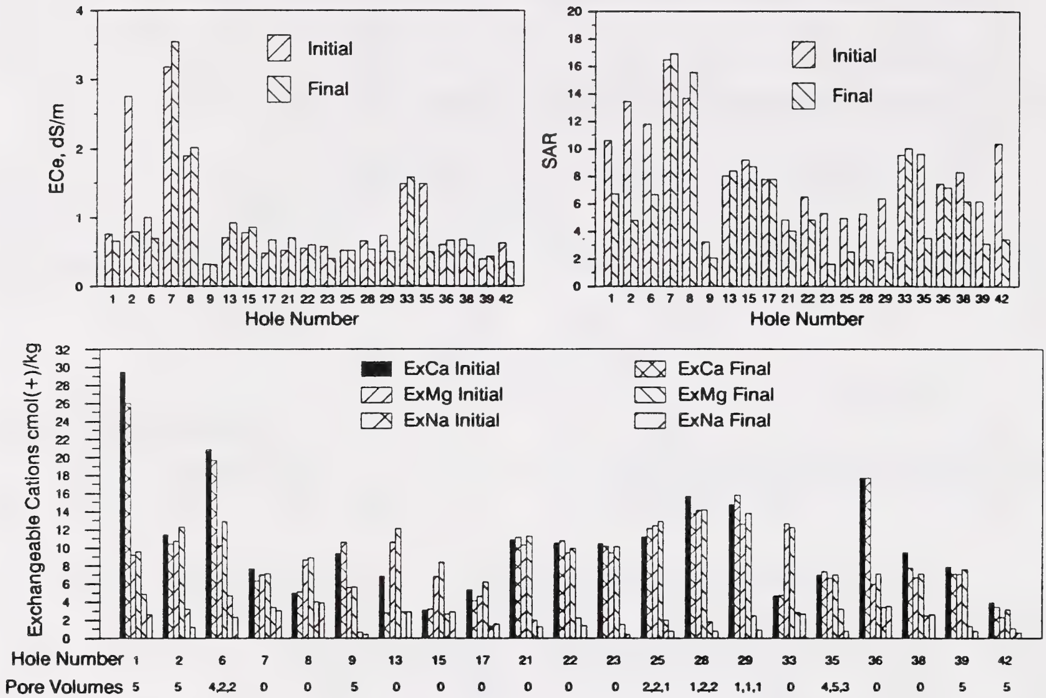

Fig.1. Comparison of soil salinity and sodicity levels and exchangeable cation content before and after the column leaching tests.

when five pore volumes were passed through the columns. Columns that were not successfully leached with five pore volumes of water exhibited considerable variation in the nature of responses observed, with several of the soils having a dramatic increase in soil salinity and sodicity, and other soils showing a sharp reduction in both ECe and SAR. Wide variation in changes in exchangeable calcium, magnesium and sodium content were also observed when values obtained before and after the leaching tests were compared (Fig. 1).

ACKNOWLEDGEMENTS

Column leaching tests were conducted by G. Slingerland, with assistance from staff in the Soil and Water Laboratory.

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GROUNDWATER RETURN FLOW IN THE WID

Joan Rodvang[1]

INTRODUCTION

Irrigation has been conducted in the Western Irrigation District (WID) since 1905, and about 80,000 acres are presently on the assessment roll of the district. An increase in the number of irrigated acres and the upgrading of existing water distribution systems has been proposed for the district. However, irrigation development may cause salinization of lands if the groundwater system is sensitive to recharge of irrigation waters. In addition, groundwater and the surface water bodies the groundwater discharges to may change in quality and quantity as a result of irrigation. In the WID, shallow bedrock and rolling topography combine to make the lands susceptible to groundwater discharge and soil salinization.

A groundwater return flow study in the Western Irrigation District will provide the information necessary to ensure that existing soil and water resources are used efficiently towards sustainable irrigation development. This investigation will be used to determine the nature of the existing groundwater-flow system, and to assess the impact of present irrigation practices on groundwater and surface water quality, and soil salinization. The expected impact of potential future irrigation development will also be assessed. The information can be used to aid in the development of effective programs for irrigation expansion and/or improvement of the existing system.

Return flow studies have been conducted in the irrigation districts of Bow River (Hendry, 1981) and Taber (Burnett, 1981), and as part of the proposed Milk River irrigation project (Robertson, 1988).

METHODS

Drilling and piezometer installation was initiated in July of 1989 along three transects oriented parallel to the dominant direction of groundwater flow. The locations of the three transects are shown in Figure 1. Piezometers will be completed at several depths at each of 24 sites. The deepest holes at each site range from 24 to 70 m below ground surface. Drilling sites have been selected to assess the role of shallow bedrock, canals, rivers and creeks, and topography, on the hydrogeology of the study area. A detailed lithological log is being prepared at each site, and samples are being submitted for chemical and particle size analysis at selected intervals. Representative holes are being geophysically logged to further refine the lithologic logs. At the time of writing, instrumentation in the overburden deposits has been completed, and drilling of deep test holes at each site is underway.

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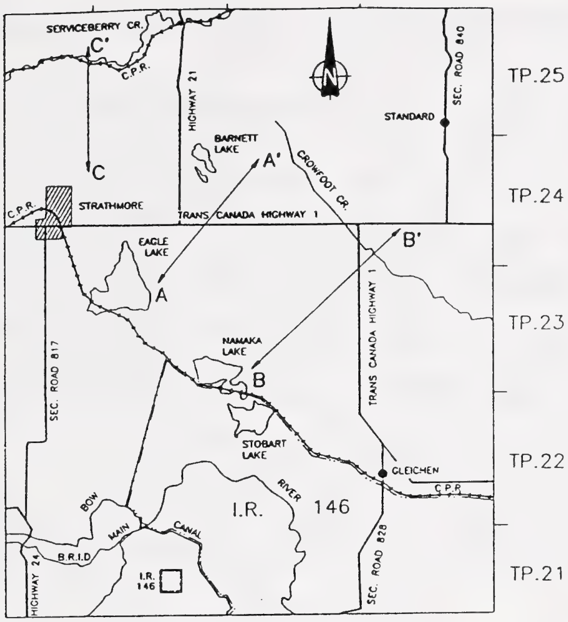

FIGURE 1: STUDY AREA

Once drilling is completed, each piezometer will be flushed and bailed at least twice, to remove any contaminants introduced during drilling. Single-well response tests will be conducted to determine the hydraulic conductivity of all geologic intervals. Water samples will be collected to define the geochemical and isotopic characteristics of the groundwater. Water levels in the piezometers and wells will be monitored at regular intervals for at least 2 years.

Using the information obtained during drilling, as well as subsequent physical and chemical groundwater testing and monitoring, the geology and hydrogeology along the three transects will be determined. A three-dimensional mathematical groundwater-flow model (MODFLOW) will be used to simulate the existing groundwater-flow regime, including recharge and discharge characteristics, and groundwater travel times. The major controls on groundwater flow, including the influence of shallow bedrock, topography, and canal seepage, will be assessed. Simulations will then be conducted using different amounts of irrigation recharge to groundwater, in order to estimate the potential impact on groundwater flow.

PRELIMINARY RESULTS

The study area lies on the eastern limb of the Alberta Syncline, with the bedrock dipping east at one to two m per km (Irish, 1967). A northwest to southeast trending bedrock ridge, which is expressed in the surface topography, runs from Strathmore to Hammer Hill.

Bedrock generally lies at 2 m depth below the bedrock ridge, falling to over 11 m in depth below valleys.

Throughout most of the study area, the subcropping bedrock unit consists of the Tertiary Paskapoo Formation, which is a buff to brown weathered, grey, medium to coarse grained fresh-water sandstone and clay shale (Irish, 1967). The Paskapoo is underlain unconformably by the Upper Cretaceous Edmonton Formation, which consists of continental to deltaic light gray argillaceious sandstone. The Edmonton subcrops below the northeastern end of cross-section BB'.

The overburden in the study areas consists of lacustrine and outwash deposits, underlain in many places by till.

Based on hydrogeological maps for the Drumheller (Borneuf, 1970) and Gleichen (Ozoray, 1970) areas, groundwater flow is expected to follow surface topography. The expected groundwater flow direction for cross-section AA' and BB' is northeast from the Strathmore-Hammer Hill ridge, towards Crowfoot Creek, which eventually drains to the Bow River. Groundwater in the area of CC' is expected to flow north towards Serviceberry Creek, which drains to the Red Deer River.

The chemical analysis of overburden samples collected during drilling indicate that salinity tends to be highest under the topographical lows, with lower salinity levels below bedrock ridges.

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RIVER ROAD IRRIGATION IMPACT STUDY

Joan Rodvang[1]

INTRODUCTION

The River Road study is one part of a follow up and expansion of the Milk River Regional Groundwater Study. The original return flow study was entitled "Potential Impact of Subsurface Irrigation Return Flow on a Portion of the Milk River and Milk River Aquifer in Southern Alberta" (Robertson, 1988). The purpose of this study was to determine the nature of the existing groundwater-flow system, and to predict the impact of irrigation on groundwater and surface water flows. This study indicated that it would require about 1000 years for irrigation return flow to reach the Milk River, and that this irrigation return flow would slightly increase the rate of groundwater quality degradation which is occurring naturally. It was predicted that the degradation of groundwater quality would have only a minimal effect on the water quality in the Milk River.

The River Road study is intended to verify the predictions of the initial study by observing actual results under irrigation. Specifically, the study is intended to determine the amount of recharge occurring under irrigation in the area. A testsite which contains three center pivots was identified within the study area (Figure 1). One pivot became operational during 1986, while the other two became operational in the following year.

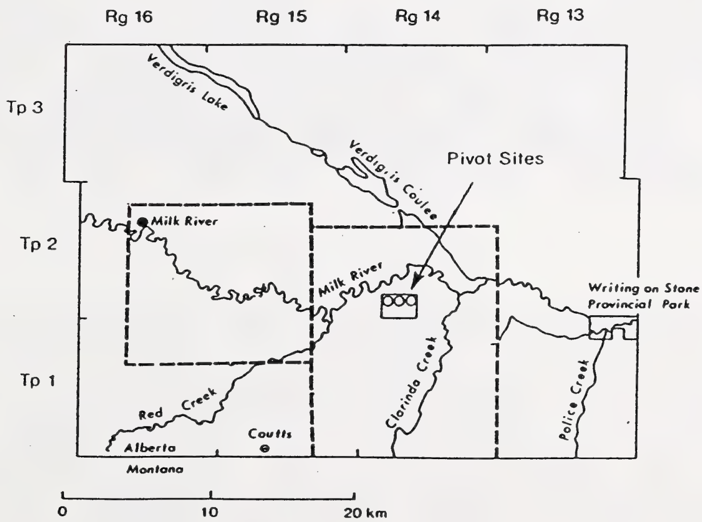

Figure 1. The Study Area.

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METHOD

Drilling of test holes and the installation of groundwater instrumentation was conducted in May of 1987. In order to measure both seasonal changes in groundwater levels and response to irrigation, monitoring of the instrumentation has been conducted on a monthly basis since installation. Twelve neutron access tubes were installed during May of 1989 to measure moisture content in the unsaturated zone. Three access tubes were installed under each pivot, with three tubes outside the pivots to act as controls. Access tube monitoring was conducted on a semiweekly basis during the spring, summer and fall to measure response to irrigation and crop growth. Soil samples are collected each spring and fall for saturation paste extract analysis (Rhoades, 1982), to determine the long-term effect of irrigation on salt leaching. The location of neutron access tubes and soil sampling sites is shown in Figure 2.

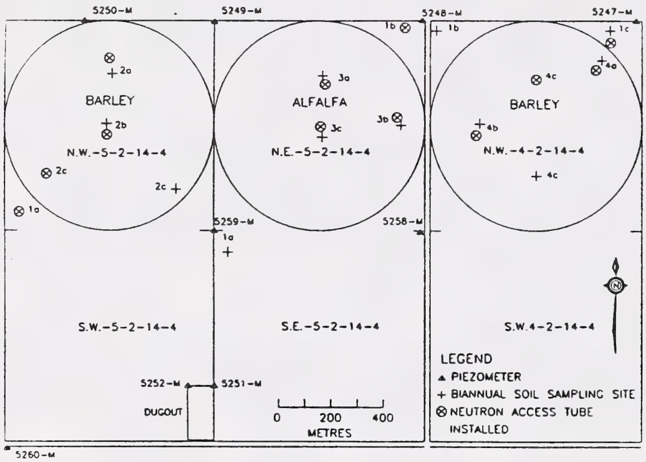

FIGURE 2 STUDY SITE

PRELIMINARY RESULTS

Topography of the River Road site slopes gently to the northeast at 10 m/km. Surface drainage is north towards the Milk River.

The surficial material below the site consists of clay loam to sandy clay loam till. A deposit of pre-glacial alluvial gravel, which is up to 2 m thick and is associated with the Milk River Valley, occurs below the till at the north end of the study site. The Milk River Sandstone is the subcropping bedrock formation. The Virgil sandstone member subcrops over most of the area, except where it is overlain by the Dead Horse Coulee member. The latter member occurs in a southwest to northeast trending strip in the centre of the site. The bedrock surface dips northeast at a rate of 20 m/km, levelling off to 5 m/km in the northeast portion of the site. Bedrock depth varies from 3 to 5.5 m below ground surface.

Groundwater flows to the northeast, following regional patterns. The water table surface dips steeply below the study area, from 2.5 to 4 m below ground in SW-5-2-14, to approximately 22 m below ground in the northeast, in NW-4-2-14 (Figure 2). The water table occurs at a depth of approximately 21 m below the pivots. A perched water table, shown as dashed lines on Figure 3, occurs at 2.5 to 4.5 m depth in the northeast corner of the study site.

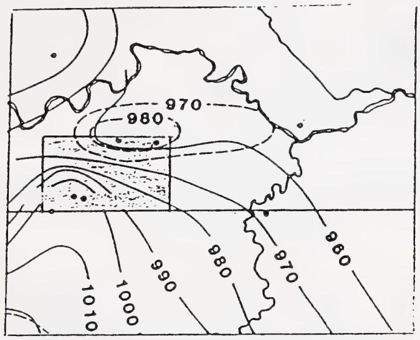

Figure 3: Water Table Elevation

Soil Moisture Content

Moisture content versus depth profiles for each plot are shown in Figure 4. These profiles were obtained by averaging the 3 readings at each depth for each pivot. The control plot (summerfallow and crested wheat grass) exhibited a higher moisture content than the irrigated fields at all depths, suggesting that the irrigation water applied was balanced by the consumptive use of the crop. From Figure 4 it appears that moisture content was lower at all depths below the alfalfa than below the other plots. Rain gauge monitoring indicated that each irrigated field received approximately the same amount of moisture, suggesting that on average the alfalfa used more moisture at all depths.

Figure 4: Moisture content averaged by plot, for July 18,1989.

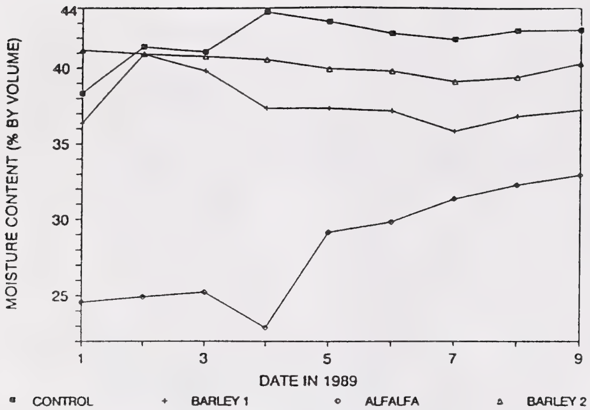

Figure 5: Moisture content averaged by plot at 120 cm depth.

Figure 5 shows the variation in average moisture content over time at a depth of 120 cm. Moisture content in the barley and control plots remained quite constant over the summer, with the control plot exhibiting the highest moisture content throughout the season. The alfalfa was cut three times, on July 6, July 27 and the end of September. The gradual increase in moisture content which was registered under the alfalfa during the 1989 season may reflect a decrease in the growth rate of the alfalfa with successive cuttings.

Soil Chemistry

Soil chemistry data was obtained on two occasions, November 1988 and April 1989. The samples were analyzed by two different labs, at significantly different saturation extract percentages. In order to compare the results, the chemistry was normalized to the average saturation percent.

Figure 6 illustrates electrical conductivity (EC) versus depth for each plot. The salt content increases with depth to 1.5 m, suggesting that a small amount of leaching has occurred. The control plot has a higher EC than the irrigated fields, and it exhibits a small accumulation zone at 105 cm, whereas EC under the irrigated fields continues to increase to 150 cm. This may indicate that the control plot has undergone slightly less leaching than the irrigated fields.

All plots exhibit a relatively low EC value, increasing from approximately 1 at the surface, to approximately 3 to 4 at depth. Sulfates of calcium and magnesium are the major salts present (data not shown).

Figure 7 compares EC values between the fall and subsequent spring samplings. No consistent trends between the two sampling dates can be discerned.

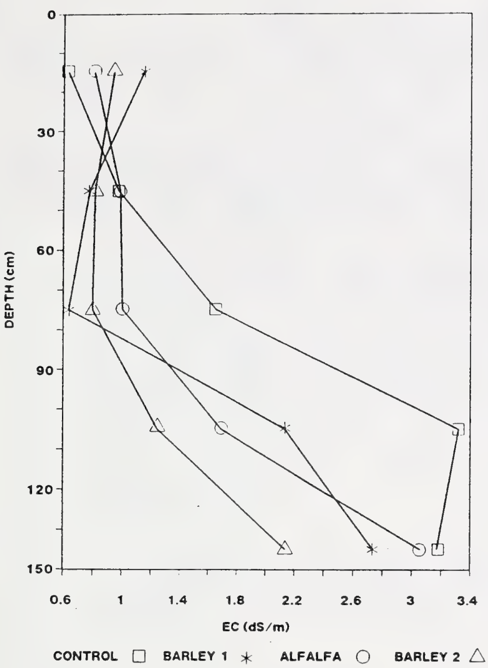

Figure 6: Soil EC averaged by plot, and averaged over two sampling dates.

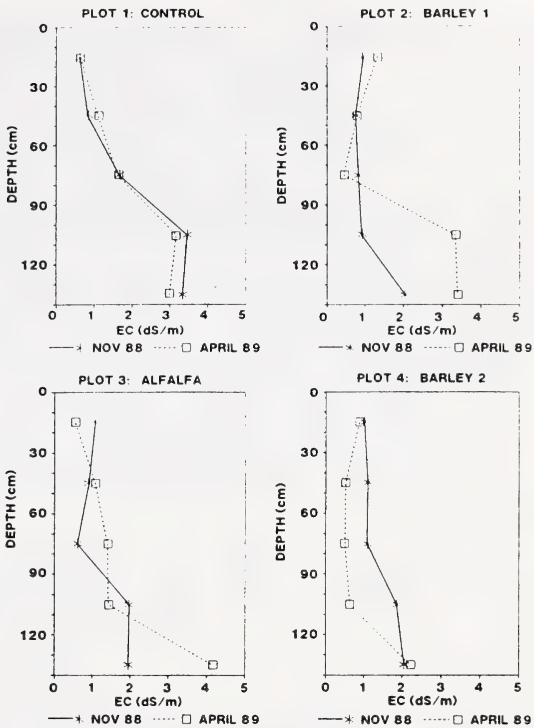

Figure 7: Plots of EC versus depth.

FUTURE WORK

Additional field work and monitoring is required to determine whether recharge is occurring. Access tubes will be extended to the bedrock, which is usually at around a 4 m depth. Soil cores will be collected for the laboratory analysis of moisture retention characteristics (Cassel and Nielsen, 1986). Soil profiles and textures will be obtained at the same time. Biannual monitoring of soil chemistry will be continued, but extended to greater depths.

In an attempt to monitor possible responses of the water table to recharge, water table wells will be installed at each pivot. As a result of the relatively great depth to the water table below the site, it will probably be difficult to detect a water table response to the recharge. However, some response in the perched water table at the northeast end of the site may be detected.

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CROP ROOTING DEPTH STUDY

Robert V. Riewe[1]

INTRODUCTION

In 1987, a project was undertaken to study the rate and depth of root development for a variety of different crops. The project was initiated in response to a paper written by H. Borg and D. W. Grimes entitled "Depth Development of Roots with Time: An Empirical Description". In this paper, an equation was developed which calculates the rooting depth based on three variables: current days after planting, days to maturity, and maximum rooting depth. Preliminary results from 1987 indicated that the equation developed by Borg and Grimes for estimating rooting depth and rate could be used for cereal crops but not for oil seed crops. Field data collected in 1987 has shown that this equation tends to underestimate rooting depth and rate for oilseed crops.

In 1988, the same project was continued with major emphasis placed on obtaining information on row and oilseed crops (i.e., sugar beets, potatoes, sunflower seeds, dry beans, and canola).

METHODS

Soil samples were taken at 25 cm increments to a depth of 2.0 m using an Eijkelkamp soil auger. Soil samples from each depth were visually inspected for live roots (only translucent colored roots were considered to be alive). At the time of sampling, additional notes were made on crop development, soil texture, soil moisture, weed problems, irrigation, and whether or not any physical obstructions exist in the rooting profile (i.e., hardpans, dry layers, salt layers, water tables, etc.). Crop information was based on the Zadok Decimal Code for Cereals (Johnstone and Macleod), Description of Sunflower Stages (Schneiter and Miller), Developmental Stages of Common Bean Plant (Lebaron), Summary of Growth Stages (Canola Growers Manual 1984), and other crops were described according to field inspections made on each soil/root sampling day.

Two soil/root sampling sites were used for each crop sample with the information being averaged for the site. Sampling sites selected for this project were done with the help of the irrigation specialists and irrigation management technologists from the Lethbridge, Taber and Vauxhall offices. The fields were selected primarily from participants on the Irrigation Management Program.

Soil/root sampling was to start once the crop had emerged and continue on a weekly basis until the crops were swathed or matured to a point where no further root development was occurring as determined by visual inspection.

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RESULTS

In 1988, a total of eight different crops in 24 fields were monitored under this project. Of these eight different crops, one was soft white spring wheat, seven canola, two dry peas, two barley, one lentil, one potato, four sugar beets, three dry beans and two sunflower fields. In total, twenty four fields were monitored.

Due to the dry seed bed conditions in 1988, 23 of the 24 fields monitored had received an irrigation immediately after seeding. One field of sunflowers was not irrigated for three weeks after seeding (surface irrigated). Barley, soft white spring wheat, canola and dry peas all showed earlier root development in 1988 as compared to those same crops in 1987. Barley, soft white spring wheat and dry peas all exhibited shallower total root development at the end of the 1988 crop growing season (Table 1).

TABLE 1

CROP	DAILY ROOTING RATE (cm/day) (average)		FINAL DEPTH (cm) (average)	
	1987	1988	1987	1988
Canola	1.65	2.40	130	140
Barley	1.70	2.15	150	130
Sugar Beets	***	1.80	***	135
Dry Peas	1.40	1.70	120	110
Dry Beans	1.70	1.90	120	120
Soft Wheat	1.65	1.90	140	120
Sunflowers	2.30	2.15	160	150
Lentils	***	1.45*	***	100*
Potatoes	***	1.70*	***	105

* Represents only a single sampling site

*** No samples taken in 1987.

The following equation was developed by H. Borg and D. W. Grimes for determining crop rooting depth:

$$RD = RDM\ [0.5 + 0.5 \sin\ (3.03\ \frac{DAP}{DTM} - 1.47)\ ]$$

RD = current rooting depth (cm)
RDM = maximum rooting depth (cm)
DAP = current days after planting
DTM = days to maturity
NOTE: All calculations to be done in radians.

Data collected from five (5) sites in 1988 has shown that the equation developed by Borg and Grimes can be used in determining the depth to which roots develop and the rate at which roots develop for soft white spring wheat, barley and dry peas (Figures 1a, 1b, 1c). This corresponds to similar findings in 1987. For row crops and oilseed crops, this equation tends to underestimate rooting rate and depth (Figures 2a, 2b, 2c), 2d).

Field results have shown that the rate and depth to which plants develop roots follows a sigmoidal pattern, similar to that of the Borg and Grimes equation, but the steepness of the curve is greater in field trials. This change in slope angle is the primary reason why the Borg and Grimes equation has been underestimating rooting depth for oilseed and row crops.

Based on the data collected in 1987 and 1988, crop rooting equations have been developed for soft white spring wheat, barley, canola, dry peas, dry beans, sugar beets and sunflowers (Table 2).

TABLE 2

CROP	EQUATION	COEFFICIENT OF DETERMINATION
Soft White Spring Wheat	Y=7.04+0.20(x)+3.93E-02(x 2)-2.24E-04(x 3)-5.87E-07(x 4)	r^2=0.89
Barley	Y=15.68-1.07(x)+0.11(x 2)-1.37E-03(x 3)+5.13E-06(x 4)	r^2=0.90
Canola	Y=22.93-4.12(x)+0.24(x 2)-3.13E-03(x 3)=1.28-05(x 4)	r^2=0.91
Dry Peas	Y=13.82-1.43(x)+0.10(x 2)-1.18E-03(x 3)+4.15E-06(x 4)	r^2=0.90
Dry Beans	Y=55.55=7.74(x)-0.25(x 2)+4.24E-03(x 3)-2.50E-05(x 4)	r^2=0.93
Sugar Beets	Y=12.59-1.35(x)+0.11(x 2)-1.12E-03(x 3)+3.18E-06(x 4)	r^2=0.90
Sunflowers	Y=16.23+2.71(x)-6.04E-02(x 2)+1.57-03(x 3)-1.14E-05(x 4)	r^2=0.89

Y = rooting depth (cm) x = days after planting

Field results have also shown that the rate of root development matches the rate of water consumed by the crop for vegetative production. As the crop enters into its critical stage of development (peak water use period), rate of root development is at its maximum. As the crop begins to mature, shifting from vegetative growth to reproductive growth, rate of root development increases but at a greatly reduced rate.

Of the 24 fields monitored in 1988, only two fields (one sunflower and on dry pea field) were affected by poor soil moisture conditions. Poor soil moisture being greater than 50% of the moisture available for crop use has been depleted from a one metre rooting zone. Poor soil moisture conditions were due primarily to limited water supply (Figure 1c) and heavy competition by weeds (Figure 2a).

In two of the fields monitored, a water table was present at approximately one metre. In both cases, the water table did not restrict root development into the saturated zone.

Poor root development in one sugar beet field (Figure 2b) is related to hail damage. Due to the reduction in plant leaf biomass, it is believed that there was a shift in nutrient flow upward from the root system for new leaf production. This shift in nutrient flow seems to be the cause of reduced root development.

CONCLUSION

Preliminary results indicate that good soil moisture conditions early in the crop growing season are crucial for good root development. With the dry seed bed conditions of 1988, irrigation water applied after seeding showed substantial increases in the rate in which roots develop for barley, soft white spring wheat, and canola compared to those same crops in 1987.

These preliminary results also indicate the importance of monitoring soil moisture conditions throughout the crop growing season. It is especially critical at the time of seeding and at the critical stage of crop production.

After two years of monitoring root development, the equation developed by H. Borg and D. W. Grimes for predicting root development is valid for cereal crops. At the present time, their equation tends to underestimate root development for oilseed and row crops. Additional field information is required on oilseed and row crops to validate this equation or whether new rooting depth equations need to be developed.

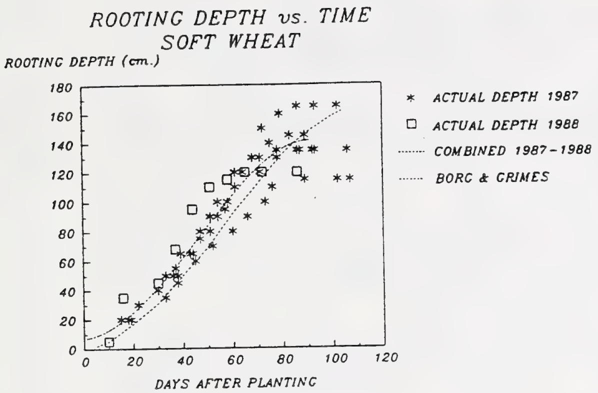

Figure 1a

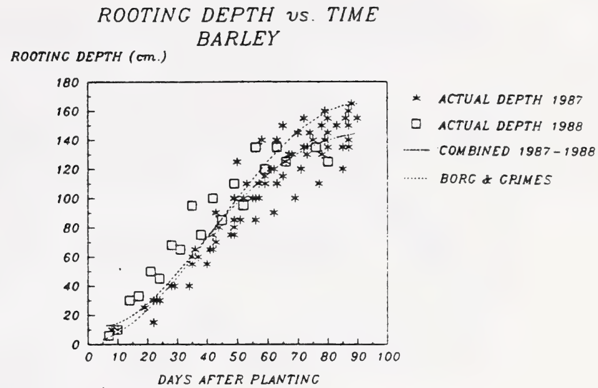

Figure 1b

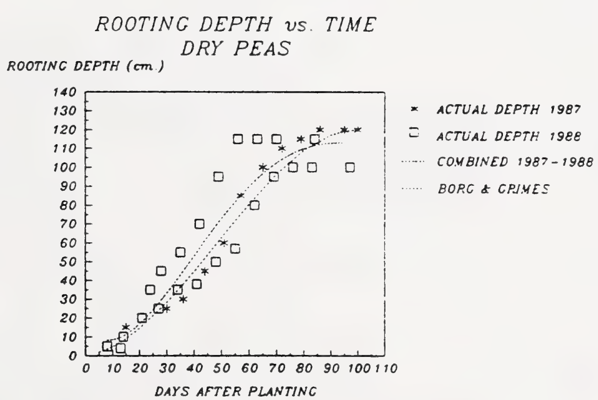

Figure 1c

ROOTING DEPTH vs. TIME
SUNFLOWERS – 1988

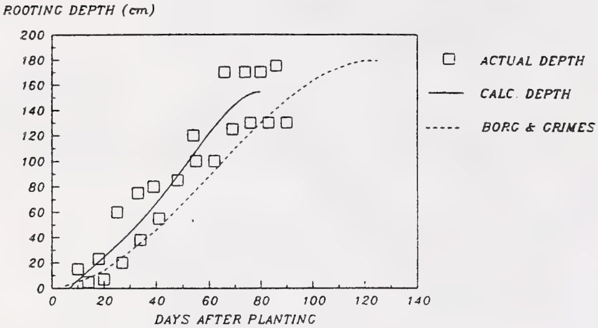

Figure 2a

ROOTING DEPTH vs. TIME
SUGAR BEETS – 1988

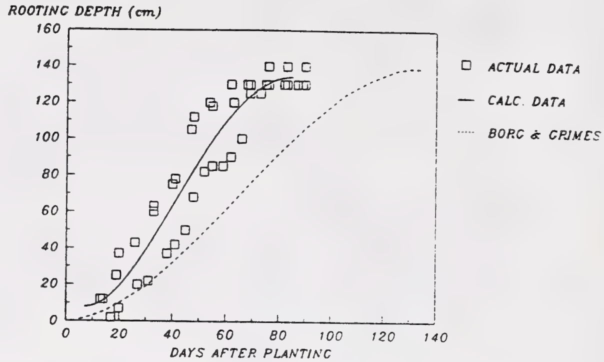

Figure 2b

ROOTING DEPTH vs. TIME
CANOLA

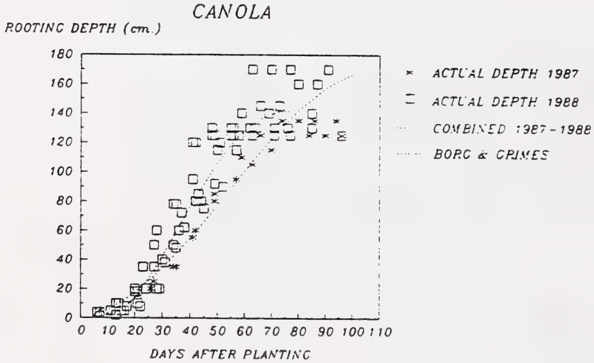

Figure 2c

ROOTING DEPTH vs. TIME
DRY BEANS

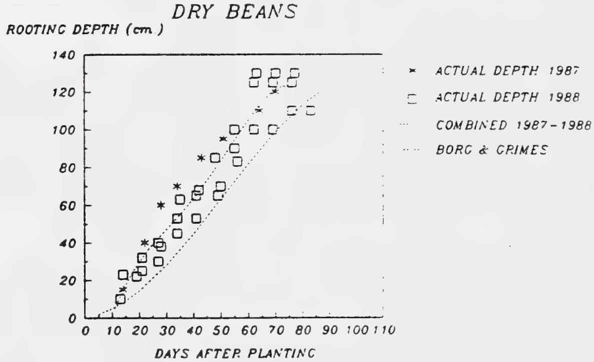

Figure 2d

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ROOTING DEPTH OF MONARDA AND SAFFLOWER

R. C. McKenzie[1]

INTRODUCTION

Monarda (Monarda fistulosa) is a new crop which is being grown as a source of fragrant oil. Trials with monarda have been carried out at Morden, Manitoba, and in Quebec. The first commercial production of this crop commenced in 1987 in Alberta near Carmangay. In 1988, a second planting was made near Bow Island. Both crops are irrigated. There is no information available about irrigation management of monarda. In the fall of 1988, the ASCHRC soils staff collected soil and root samples to measure the rooting depth of Monarda.

Safflower is a crop which has recently been grown in Alberta as an irrigated crop. It has also been grown under irrigation in New South Wales, Australia. In Australia it is grown in rotation with cotton to dry out soils and improve drainage by extending its tap root into the subsoil. In Montana, safflower is grown as a deep-rooted crop to dry out recharge areas in saline seeps. In 1987 and 1988, the soils and agronomy section of ASCHRC carried out an experiment to determine the influence of different irrigation treatments on the yield and quality of safflower. No information is available on the rooting depth to use for irrigation scheduling. In the fall of 1988, soil samples were collected to determine the rooting depth of safflower.

METHODS

Soil and root samples were taken with a drill truck equipped with a push tube 5 cm in diameter. At each site four samples were taken. Monarda was sampled at two sites: plots ASCHRC's Lendrum Farm and at Carmangay. Safflower was sampled at the irrigation plot site north east of Duchess and at the ASCHRC special crops plot site near Standard. Soil samples were taken in 30-cm intervals to a depth of 150 cm for monarda and to a depth of 240 cm for safflower.

Root samples were washed in a root washing machine constructed and operated by the soils department of the Alberta Environmental Centre at Vegreville. Samples were enclosed in a fine mesh screen and subjected to jets of water and air to remove soil particles. The root samples were floated to the top and collected.

Lengths of roots were determined by a computer program which measured the number of intercepts of beam of light on a photograph of the root samples. Lengths of roots were not determined for the 0-30 cm depth as this sample contained contamination from soil organic matter. Root samples obtained from the washing procedure were dried and weighed.

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RESULTS

Monarda had considerable roots (Fig. 1) present to 1.20 m in the Carmangay samples and to 1.50 m in the Lendrum samples. Monarda root weights were less than 1 g per sample below 0.30 m (Fig. 2) for both sites. The plants at both sites were 1 year old and may not have had a fully developed root system. The plants at the Carmangay site were delayed in growth because they were harvested for oil during 1988. It is not known if the Lendrum site had some contamination from roots of adjacent crops.

A rooting depth of 1.20 m should be suitable for irrigation scheduling of Monarda. For an irrigation scheduling program, both rooting depth and acceptable level of moisture stress should be known. No data are available on the tolerance of monarda to moisture stress.

Safflower had considerable roots to 1.20 m at Duchess and to 1.50 m at Standard (Fig. 3 and Fig. 4). The site at Standard had more growth than the one at Duchess. A rooting depth of 1.20 m is suitable for irrigation scheduling although safflower does take moisture from below this depth. At the Duchess site, the unirrigated treatment used 35% of the available water from 1.20 to 1.50 m but used only 4% of the available moisture from 1.50 to 2.10 m.

Fig. 1

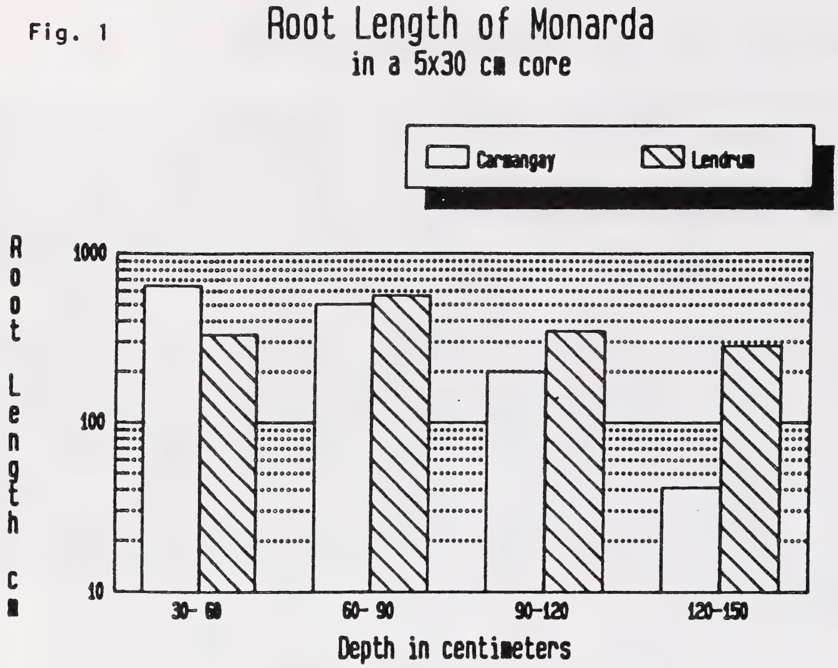

Root Length of Monarda
in a 5x30 cm core
Carmangay
Lendrum
Root Length cm
1000
100
10
30- 60
60- 90
90-120
120-150
Depth in centimeters

Fig. 2

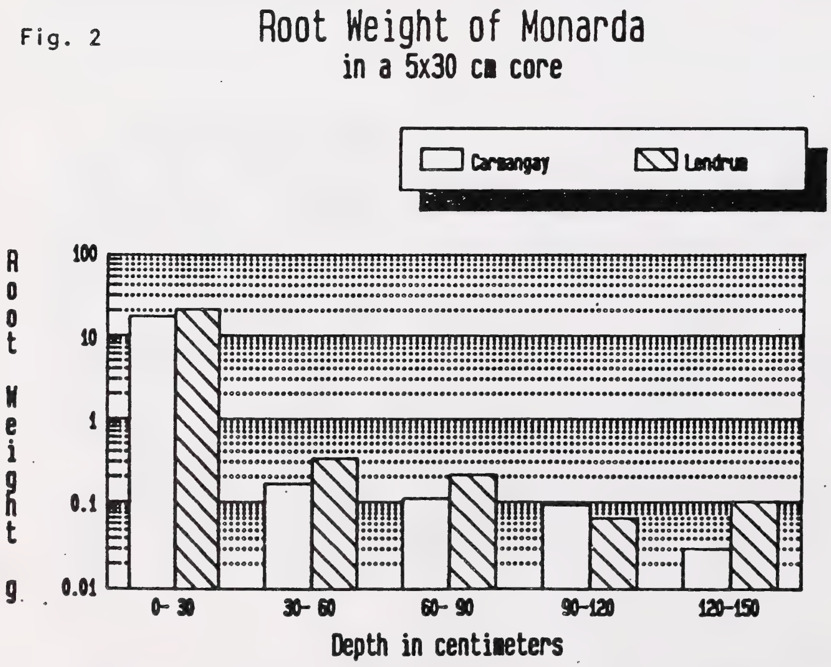

Root Weight of Monarda
in a 5x30 cm core
Carmangay
Lendrum
Root Weight g
100
10
1
0.1
0.01
0- 30
30- 60
60- 90
90-120
120-150
Depth in centimeters

Fig. 3

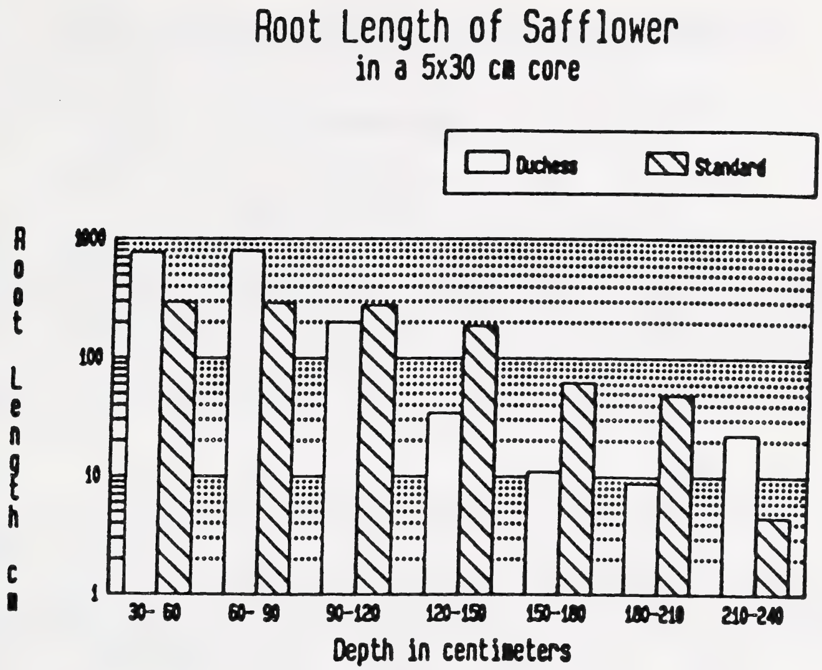
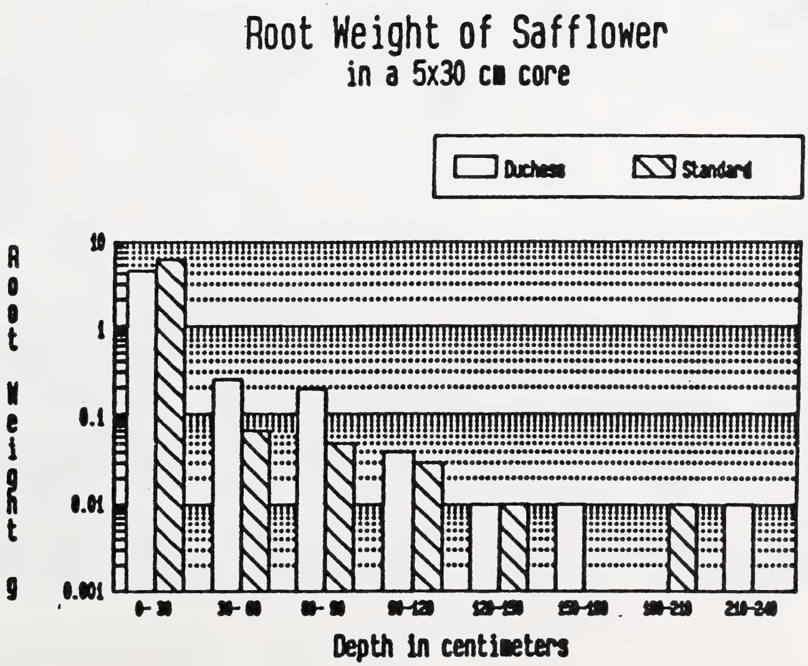

Root Length of Safflower
in a 5x30 cm core
Duchess
Standard
Root Length cm
1000
100
10
1
30- 60
60- 90
90-120
120-150
150-180
180-210
210-240
Depth in centimeters

Fig. 4


Root Weight of Safflower
in a 5x30 cm core
Duchess
Standard
Root Weight g
10
1
0.1
0.01
0.001
210-240
Depth in centimeters

THE EFFECTS OF IRRIGATION ON TWO CULTIVARS OF LENTILS

R. C. McKenzie and N. F. Clark[1]

INTRODUCTION

In 1988, an experiment was conducted on the water requirement of lentils. It was the continuation of a project started in 1987 to measure the water use of lentils and to determine the effect of irrigation on yield, quality, and maturity of the seed.

MATERIALS AND METHOD

In 1988, two cultivars of lentils were grown at four levels of irrigation: Laird, a late maturing variety with large seeds, and Eston, an early-maturing variety with small seeds. They were seeded on May 3, Eston at 46 kg/ha and Laird at 90 kg/ha.

For soil samples taken prior to seeding, analyses are reported in Tables 1, 2, and 3. Prior to seeding, 450 kg/ha of fertilizer (12-51-0) was applied to the plot site with a Gandy applicator. Ethalflurin, a pre-emergent weed control chemical, was incorporated into the soil. A dry seedbed delayed germination of lentils and resulted in a severe infestation of Russian thistle. The lentils were plowed down on May 31. On June 1, the plot was reseeded into the same area to prevent varietal contamination. The treatment areas were hand weeded, and late in the season the guard areas were disked under to control the Russian thistle.

Table 1. Soil fertility analyses (in ppm) of lentil plot site.

Depth (cm)	K	PO_4-P	NO_3-N	NH_4-N	SO_4-S
0-15	332	12.2	1.0	5.0	5.1
15-30	174	3.8	1.0	5.5	3.6
30-60	133	1.8	1.0	4.5	12.9

The experiment consisted of four water treatments labelled as W0, W1, W2, and W3 and four replicates (Table 3). The water treatments consisted of a plot 7.6 x 7.6 with a guard area of 10.7 m between water treatments. Water treatments varied from no irrigation on W0 to a number of small irrigations on W3 to keep the available moisture above 70% field capacity. The other treatments are W1 which received

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Table 2. Characterization of the soil in the lentil plot site.

Depth	EC dS m^{-1}	pH	SAR	Na meg L^{-1}	% S	% Si	% C	Texture
0-30	0.6	7.4	0.3	0.5	55	22	23	SCL-SL
30-60	0.9	7.9	0.4	0.8	53	23	24	SCL-L-SL

one large irrigation in midseason, and W2 which received two large irrigations during the season. Since the seedbed was dry, W0 received a small irrigation to ensure germination of the seed.

RESULTS AND DISCUSSION

Soil moisture records were kept over the season for a root zone of 0.9 m. Initial and final moisture samples were taken to 1.5 m and these records, along with amounts of irrigations and rainfall, were used to determine water use. These amounts for each variety and irrigation treatment are listed in Table 3.

Table 3. Soil water holding capacity of lentil plot site.

Depth	DB	Fc %	PW %	Available moisture mm/0.3 m
0- 30	1.48	21	9	50
30- 60	1.48	21	9	53
60- 90	1.45	23	10	54
90-120	1.44	23	10	53
120-150	1.47	21	9	53

The consumptive use of the lentils over the growing season was similar for W0 and W1 in both varieties. This occurred in spite of the W1 treat ment receiving 90 mm of irrigation water. The W0 treatment depleted the available soil moisture by 110 mm more than the W1 treatment. The stress placed on the plants in the W0 treatment is reflected in the yield (Table 4) with W1 producing about twice as much seed in both varieties. The maximum yield of Laird (1203 kg/ha), the late maturing variety, was achieved on the W1 treatment (Table 5). Higher rates of irrigation reduced yield. This was in contrast to the short season variety, Eston, which produced a significantly higher yield of 3578 kg/ha on the W3 treatment than on the other treatments.

Table 4. Irrigation, rainfall, soil moisture depletion and consumptive use (in mm) of two varieties of lentils grown under four irrigation treatments.

	Rainfall#		Irrigation	Depletion to 1.5 m		Consumptive Use	
Treatment	Eston	Laird	Eston & Laird	Eston	Laird	Eston	Laird
Water 0	151	173	9	109	89	269	271
Water 1	163	173	90	-1	8	254	271
Water 2	163	173	176	14	-44	398	324
Water 3	173	173	323	-26	-70	470	426

Rainfall differs due to different harvest dates.

Table 5. Seed yield and protein content of two varieties of lentils grown under four irrigation treatments.

	Yield (kg/ha)		% protein at 13.5% moisture	
	Laird	Eston	Laird	Eston
W0	658	977	22.3	24.4
W1	1203	2166	23.0	22.1
W2	1193	2431	21.4	21.4
W3	590	3578	22.7	23.2
LSD#	591	339		2.0
F	3.41	6.84*	1.7	4.3

LSD according to Waller and Duncan determined at the 100:1 seriousness level (analagous to the 5% level).

* F value significant at the 5% level.

In 1988, both varieties of lentils did not have fungal infections in contrast to 1987 when fungal infections were severe. All of the lentils were harvested by September 15, 1988. There was no frost up to this date. Reseeding the plot did not affect Eston, but the Laird lentils matured unevenly.

CONCLUSIONS

Lentils prefer cool weather during the flowering period. The late seeding date moved the flowering period into the warmer part of the growing season. This affected the Laird lentils by causing uneven maturity on the W2 and W3 treatments.

Fungal growth was not a problem on any of the irrigation treatments on the 1988 crop. The 1988 site was well drained and weed free, and August was warm and dry.

The 1987 site had a fine textured soil with a low infiltration rate. This combined with a late-season, volunteer alfalfa growth, which sheltered the crop, and above normal rainfall in August, to create a sheltered, moist environment which favored fungal growth.

Eston appears to tolerate high rates of irrigation better than Laird.

In 1988, the water use of Eston was between 400 and 500 mm.

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THE EFFECT OF IRRIGATION ON TWO CULTIVARS OF SAFFLOWER

R.C. McKenzie[1]

INTRODUCTION

Two cultivars of safflower, Saffire and S208, were grown under four rates of irrigation (W0, W1, W2, and W3) at two sites. The object of the experiment was to determine the water use of safflower, the depth at which safflower extracted water from the soil, and the effects of irrigation treatments on yield and quality of seed.

METHOD

The sites were 6 km northeast of Duchess (SE15-21-14-W4) on a sandy clay loam soil and near Rolling Hills on a silty clay soil. Both sites were very dry after seed bed preparation. Due to lack of labor, sprinkler systems were not in operation until 2 weeks after planting. Because of poor emergence, the Rolling Hills site was abandoned and the stand of Saffire at Duchess was too thin to be used to collect data. Yield and water use data were collected for S208 at the Duchess site.

Before seeding, soil samples were taken for fertility and physical analysis (Tables 1 and 2). After harvest, soil samples were taken to 2.4 m to determine the effect of irrigation treatments on salinity and nitrogen contents. Soil moisture determinations by thermogravimetric method were made during the season to 1.5 m, and before seeding and after harvest to 2.4 m.

Table 1. Soil conductivity, pH, available water holding capacity and texture of the safflower plot site.

Depth m	EC	pH	Available moisture (mm/30cm)	Texture S %	Si %	Cl %	
0.00-0.30	0.9	7.4	54	48.3	23.7	28.0	SCL-L
0.30-0.60	3.8	7.8	58	45.3	28.7	26.0	SCL-CL
0.60-0.90	6.4	8.0	51	46.0	29.3	24.7	CL-SCL
0.90-1.20	7.9	8.0	51	48.0	28.3	23.7	SCL
1.20-1.50	7.8	8.0	52	48.7	26.7	24.7	SCL-L
1.50-1.80	8.2	7.9	52	48.7	26.0	25.3	SCL-L
1.80-2.10	8.3	7.9	49	50.0	22.3	27.7	SCL
2.10-2.40	7.9	7.8	45	50.3	22.3	27.3	SCL

[1] Alberta Special Crops and Horticultural Research Center, Brooks, Alberta

Table 2a. Soil Analysis before Spring 88 seeding of the safflower plot site

Depth	NH_4-N	NO_3-N	K	EC
m	ppm	ppm	ppm	ds/m
0.00-0.30	4.8	3.0	176	1.0
0.30-0.60	4.0	6.2	144	1.8
0.60-0.90	3.5	7.8	160	3.7
0.90-1.20	4.5	6.2	177	7.5
1.20-1.50	4.5	5.5	178	8.2
1.50-1.80	5.5	7.2	178	8.2
1.80-2.10	6.0	9.2	175	8.0
2.10-2.40	5.0	10.0	184	7.4

Table 2b. Soil analysis after harvest of 4 water treatments from the safflower plot site.

	Water 0				Water 1			
Depth	NH_4-N	NO_3-N	K	EC	NH_4-N	NO_3-N	K	EC
m	ppm	ppm	ppm	ds/m	ppm	ppm	ppm	ds/m
0.00-0.30	4.5	12.5	306	0.45	3	2.5	511	0.35
0.30-0.60	5.0	14.0	173	1.20	4	12.0	159	0.70
0.60-0.90	5.0	36.0	166	2.90	6	10.0	158	2.20
0.90-1.20	5.0	14.0	185	4.20	4	9.0	188	5.60
1.20-1.50	4.0	5.0	204	5.30	4	4.0	183	6.30
1.50-1.80	4.0	5.0	204	5.30	5	4.0	195	6.10
1.80-2.10	4.0	4.0	229	4.00	4	4.0	180	6.20
1.80-2.40	4.0	5.0	218	3.30	4	4.0	206	5.00

	Water 2				Water 3			
Depth	NH_4-N	NO_3-N	K	EC	NH_4-N	NO_3-N	K	EC
m	ppm	ppm	ppm	ds/m	ppm	ppm	ppm	ds/m
0.00-0.30	3	0	481	0.	3	0.5	577	0.25
0.30-0.60	4	7	199	0.9	3	9.0	205	2.40
0.60-0.90	4	1	141	0.4	3	20.0	209	3.60
0.90-1.20	6	5	220	4.0	3	17.0	225	3.70
1.20-1.50	5	11	205	3.0	3	9.0	221	5.40
1.50-1.80	5	4	208	5.0	6	6.0	221	5.70
1.80-2.10	5	5	214	5.4	5	9.0	232	5.40
2.10-2.40	5	8	223	5.2	5	10.0	244	4.50

Safflower, variety S208, was seeded on May 3 at the Duchess site at a rate of 30 kg/ha for S208. Prior to seeding, the herbicide, Edge, was applied at 0.80 kg/ha and incorporated and ammonium phosphate fertilizer was broadcast and incorporated to provide 36 kg/ha N and 73 kg/ha P.

To control sclerotinia, the crop was sprayed with a fungicide, Benlate, three times during August and September. To topkill, the crop was sprayed with Reglone on September 28 and harvested with a small plot combine on October 14.

RESULTS AND DISCUSSION

Yield of S208 was low due to a thin stand. Water treatments W1, W2 and W3 yielded significantly more than the unirrigated control W0 (Table 3). In 1987, S208 declined appreciably in yield with increasing amounts of irrigation water. This did not occur in 1988 possibly because of the application of Benlate to control sclerotinia infections in the seed heads.

Table 3. Yield % Protein and % Oil of S208 Safflower

Treatment	Yield (kg/ha)	Protein (%)	Oil (%)
Water 0	596	16.2	36.8
Water 1	968	15.8	36.9
Water 2	1308	15.4	34.9
Water 3	1222	14.6	31.4
F*	6.8*	1.0	5.7*
LSD	367		3.4

*F value significant at the 5% level.

LSD determined according to Waller and Duncan (1969) at 100:1 error seriousness ratio (analogous to the 5% level).

In 1988, safflower grown under W3 had a significantly lower oil content (31.4%) than the other three treatments (34.9-36.9) (Table 3). In 1987, safflower grown under W3 had about one-half the oil content (17.8%) of W0 (30.7%).

Water use in 1988 (Table 4) was 126 and 165 mm more, respectively, on W2 and W3 than in 1987. The 1987 site was surrounded by irrigated crops and in 1988 the experimental site was adjacent to an unirrigated fallow field. The fallow would increase the air temperature and lower the relative humidity and thus increase the water use of the safflower crop.

In the W0 treatment, all available soil moisture was extracted to 90 cm. From 0.90-1.20 m, 1.20-1.50 m, and 1.50-2.10 m, 90, 35 and 4% respectively of the available moisture was used. On the W0 treatment, 1.20-1.50 m is the maximum effective depth of moisture extraction. Root samples of safflower were collected from the Duchess plot and results are reported in the following section "Rooting Depth of Monarda and

Safflower." Hard red spring wheat has the ability to withdraw most available moisture to 0.90 m and about one-half of the available moisture from 0.90-1.20 m. At the Duchess site safflower had an effective rooting depth about 0.30 m more than hard red spring wheat.

Table 4. Rainfall, irrigation, depletion of soil moisture, and consumptive use in mm for the safflower plot.

			Depletion		Consumptive
	Rainfall	Irrigation	0.0-1.2 m	1.2-2.4 m	Use
Water 0	262	70	+45.0	+18.0	395
Water 1	262	196	+ 3.0	+27.0	488
Water 2	262	326	+15.0	+ 2.0	605
Water 3	262	413	- 6.0	+11.0	680

RECLAMATION OF A SALINE-SEEP SOIL USING IRRIGATION AND SUBSURFACE DRAINAGE, ALONE AND IN COMBINATION

G. D. Buckland[1] and M. J. Hendry[2]

INTRODUCTION

Two common management practices for controlling soil salinity are subsurface drainage (Bennett et al. 1982; Vander Pluym et al. 1985) and irrigation management (McMullin et al. 1983). The two methods, however, have not been compared simultaneously under similar site conditions, nor has the interaction of the two been assessed. Thus, the relative merits of subsurface drainage under nonirrigated (dryland) vs. irrigated conditions, and of irrigation with and without subsurface drainage, have not been reported. This report describes results of a three-year study undertaken to differentiate reclamation rates of dryland and irrigation drainage and of irrigation without drainage.

METHODS

Treatments of irrigation (I), drainage (D) (1.2-m depth), irrigation x drainage (ID) and control (C) were established using a three replicate nested design within a 2 ha dryland saline seep south of Taber. The seep is caused by regional groundwater flow which discharges from underlying bedrock (Hendry and Buckland 1990).

Groundwater instrumentation was established in each treatment with two monitoring locations present in each replicate. Instrumentation at each location consisted of a piezometer installed at a depth of 2.4 m and a 2.0-m deep water-table well. For the ID and D treatments all instrumentation was installed at drain midspacing.

In May of 1986, prior to irrigation, soil samples were collected at all monitoring locations at depths of 0-0.15, 0.15-0.30, 0.30-0.60, 0.60-0.90 and 0.90-1.20 m. Thereafter, soil samples were collected at the same locations and depth increments following completion of irrigation in October 1986, 1987 and 1988 and before irrigation in May 1987 and 1988. Saturation extracts of the soil samples were analyzed to determine electrical conductivity (ECe) using standard methods.

Sprinkler irrigation was conducted from June through September during 1986, 1987 and 1988 for either 5 or 6 hr per day and 2 or 3 days per week. Water applied by irrigation was measured with a 1.2-m dia. calibrated pan placed about 3 m from the instrumentation. Total irrigation applications between soil samplings are given in Table 1.

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Evaporation was measured on site using a Class A pan. Potential evapotranspiration (ETp) was estimated using pan coefficients of Doorenbos and Pruitt (1977). Rainfall was recorded on site. Class A pan evaporation, rainfall and ETp are given in Table 1.

During 1986 and the first part of 1987, the piezometers and water-table wells were monitored on the day prior to irrigation. Irrigation was then conducted for three consecutive days, and on the fifth day, the piezometers and water-table wells were monitored (about 20 hr after stopping irrigation). During the latter part of 1987 and all of 1988, monitoring was conducted immediately prior to irrigation. Irrigation was conducted for two consecutive days and the piezometers, water-table wells and tensiometers were monitored on the third day.

Table 1. Water budget between spring and fall soil samplings.

	1986	1987	1988
Rainfall, mm	185	221	158
Irrigation, mm	893	774	726
Class A Pan Evaporation, mm	979	1232	1125
Pan Coefficient	0.54	0.53	0.52
ETp, mm	527	647	585
Net Surplus/Deficit			
Irrigated	551	348	299
Dryland	-342	-426	-427

RESULTS

Patterns in groundwater fluctuations during the irrigation season were similar for all monitoring years. Therefore, only representative data for 1987 are given. During irrigation (June 2 to September 17) the water table in the I and ID treatments exhibited a cyclic rise-and-fall pattern according to post-and pre-irrigation readings (Figure 1a). The water table in the D and C treatments fell gradually throughout May to August, responding only slightly to rainfall events. A 54-mm rainfall on August 16 (Figure 1c) resulted in a sharp rise in the water table of the C treatment but only a slight and time-lagged rise in the water table of the C treatment. A similar response in the water table of the D and C treatments resulted from a 59-mm rainfall on September 25, 1986. Over the three irrigation seasons, the average water-table depth for the I, ID, D and C treatments, respectively, were 0.33, 0.41, 1.05 and 0.83 m.

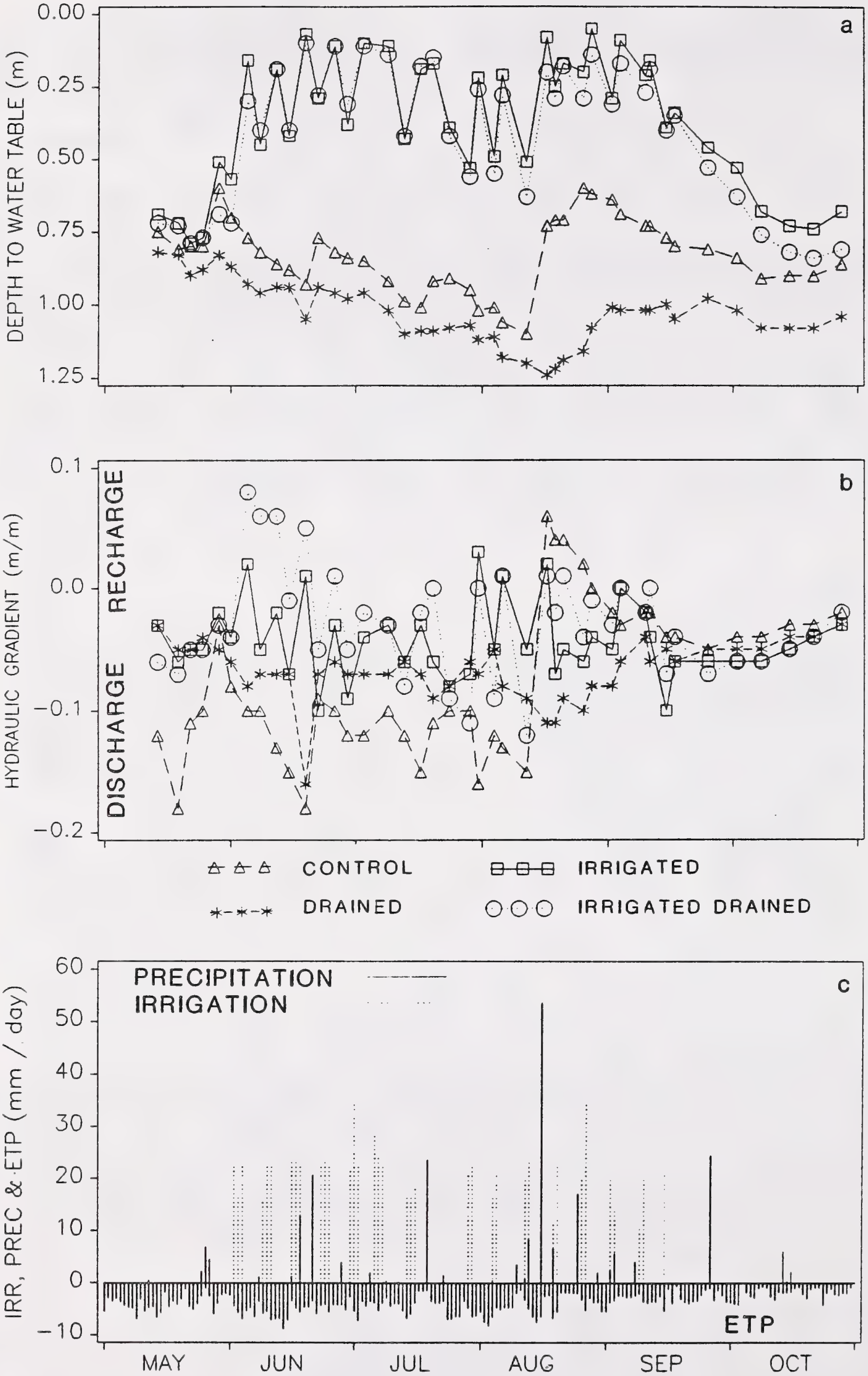

Figure 1. Detailed a) water-table fluctuations and b) piezometer gradients as related to c) daily irrigation, rainfall and potential evapotranspiration (ETP) during 1987.

Hydraulic gradients between the 2.4-m piezometers and the water table are shown in Figure 1b. Gradients for the I and ID treatments also exhibited a cyclic rise-and-fall pattern in response to irrigation events. Pre-irrigation gradients were generally discharge while post-irrigation gradients were occasionally recharge. Gradients in the D treatment were always discharge. Gradients in the C treatment were also discharge, except following the 54-mm rainfall of August 16 where recharge conditions were observed. Recharge gradients in the C treatment also occurred in response to the 59-mm rainfall on September 25, 1986. Over the three irrigation seasons, the average hydraulic gradients were -0.04, -0.02, -0.06 and -0.09 m/m for respective treatments of I, ID, D and C.

Following the first year of leaching, the relative reduction in soil salinity followed the sequence I>ID>D>C (Table 2). Reclamation was most pronounced in the 0 to 0.15-m depth and decreased with increasing depth for all treatments. Resalinization occurred between October 1986 and May 1987 in the I, ID and D treatments throughout sampling depth but was most pronounced in the 0 to 0.15-m depth. The C treatment also resalinized at the surface (0 to 0.15 m) but on average salinity decreased in the profile (0 to 1.20 m). Following the

Table 2. Initial soil salinity levels before irrigation in June 1986 (EC_o) and subsequent relative salinity levels (EC/EC_o) for the four treatments†

Treatment	EC ($dS\ m^{-1}$) June 1986	EC/EC_o Oct. 1986	May 1987	Oct. 1987	May 1988	Oct. 1988
0 to 0.15 m depth						
Irrigated	51.5	0.14	0.69	0.23	0.42	0.48
Irrigated Drained	34.9	0.27	0.48	0.23	0.47	0.37
Drained	21.3	0.58	0.78	0.80	1.38	1.55
Control	45.5	0.72	0.88	0.81	0.95	1.11
0 to 0.60 m depth						
Irrigated	49.8	0.36	0.70	0.41	0.52	0.53
Irrigated Drained	35.3	0.51	0.59	0.43	0.55	0.46
Drained	28.1	0.92	0.92	0.87	1.08	1.05
Control	38.3	1.02	0.93	0.88	0.86	0.96
0 to 1.20 m depth						
Irrigated	42.0	0.54	0.76	0.58	0.67	0.67
Irrigated Drained	27.9	0.64	0.72	0.59	0.70	0.60
Drained	25.7	0.93	1.01	0.92	1.14	1.04
Control	29.3	1.09	0.96	0.93	0.93	0.99

† Values within each depth x year x treatment cell are means of six sampling locations.

second year of leaching the relative salinity of the I and ID treatments were nearly identical and were about 60% of the original levels in the 0 to 1.20-m depth. Salinity levels in the D and C treatments were also nearly identical at all depths and were about 90% of original levels in the 0 to 1.20-m depth. Resalinization also occurred between October 1987 and May 1988 in the I, ID and D treatments and in the surface 0.15-m depth of the C treatment. Following the third year of leaching, the relative salinity followed the sequence ID>I>C>D. Leaching during 1988 occurred only in the ID treatment but final salinity levels in this treatment were slightly higher in October 1988 compared to October 1987.

DISCUSSION

The similarity in the relative reclamation of the I and ID treatments suggests that irrigation has had the greatest influence in removing salt from this soil and that subsurface drainage has a lesser effect. Changes in hydraulic gradients from discharge to recharge (or less intense discharge) following irrigation has likely caused the extent of reclamation observed. Thus, irrigation has modified both the water-table levels and potential direction of shallow groundwater flow in this saline seep soil. The value of irrigation is further attested in the greater salt removal in the I and ID treatments compared to the D and C treatments. The gradual progression of restricted leaching in the I and ID treatments from 1986 to 1988 is believed to result from the progressively lower irrigation applications on a yearly basis (Table 1).

Limited salt removal occurred on a seasonal basis in the D and C treatments despite average water tables of about 1.0 m in depth and upward hydraulic gradients. The slight reclamation achieved in the C treatment is believed to have resulted from extended rain-free periods which allowed recession of the water table, followed by periods of high rainfall. This resulted in recharge gradients in the C treatment which allowed the leaching of salts. In the D treatment, recharge gradients were not observed and thus no net salt removal occurred during the three years.

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IRRIGATION CAPITAL WORKS (ICW) RECLAMATION EFFECTIVENESS STUDY

K. M. Riddell and D. R. Bennett[1]

INTRODUCTION

The Irrigation Capital Works (ICW) Reclamation Effectiveness Study represents a continuation of research by the Land Evaluation and Reclamation Branch into the effectiveness of various seepage control measures on saline soil reclamation. The study responds to a need to document reductions in seepage-affected land associated with the existing ICW canal rehabilitation program (Coopers and Lybrand 1987).

Previous research into post-canal rehabilitation water table and salinity levels adjacent to canals in the Lethbridge Northern, Raymond, St. Mary River and Taber Irrigation Districts suggests the elimination of seepage from leaky canals does not necessarily guarantee rapid reclamation (Bennett 1990). High water table/salinity levels adjacent to canals are also influenced by surface drainage, local and regional groundwater flow, and the internal drainage characteristics of the soil and underlying geologic materials (Bennett 1990; Millette et al. 1989). Installation of subsurface drainage, improvement of surface drainage, changes in irrigation practices and/or control of groundwater recharge may be necessary to achieve reclamation within a suitable time frame in areas adjacent to canals.

The current study builds on the findings of previous research (Bennett 1990) and has the following objectives:

1. To provide a landscape model of each saline/waterlogged area prior to canal rehabilitation. Soil profile information, near surface stratigraphy (0 - 4.5 m), water table conditions, surface drainage, current and historic irrigation/farming practices and available hydrogeologic information will be incorporated.
2. To monitor fluctuation of the water table and changes in the spatial and vertical distribution of salts within affected land units following canal rehabilitation.
3. To establish benchmark sites for long-term monitoring of salinity/water table conditions and indirect evaluation of various canal rehabilitation methods.

METHODS

Site selection was limited to saline/waterlogged areas adjacent to canals scheduled for rehabilitation in the fall of 1989. Sites factors considered included: severity and extent of saline/waterlogged soils,

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extent of Solonetzic soils, rehabilitation method, type of irrigation system, farmer co-operation and ease of access. Five sites located within five irrigation districts in southern Alberta were selected (Figure 1). A wide range of canal rehabilitation methods and irrigation systems were selected (Table 1).

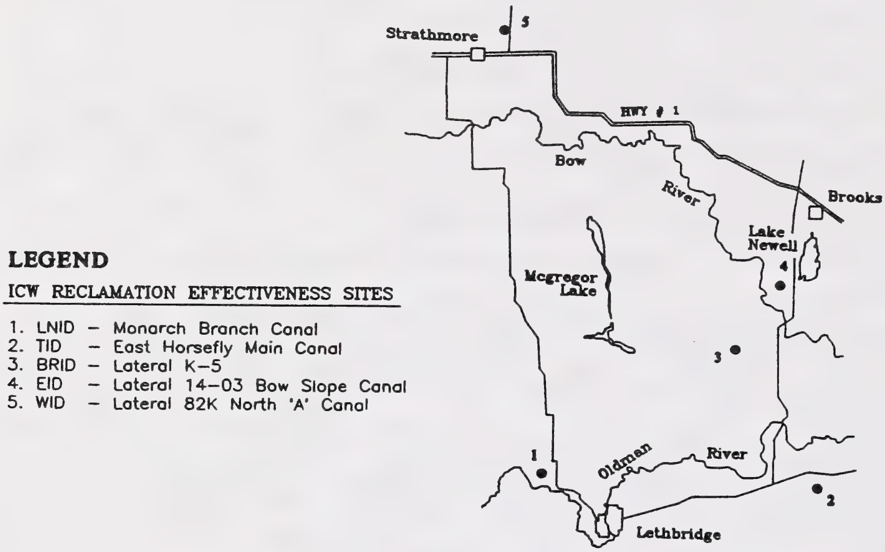

Figure 1. Location Map for ICW Reclamation Effectiveness Sites.

Table 1. Name of Canal, Rehabilitation Method and Type of Irrigation System for each ICW Reclamation Effectiveness Site.

Site #	Irrigation District	Canal	Rehabilitation Method	Type of Irrigation System
1	LNID	Monarch Branch	Grid Drainage	Sprinkler (wheels)
2	TID	East Horsefly Main	Canal Relocation	Sprinkler (wheels & pivot)
3	BRID	Lateral K-5	Reshaping Polylining	Flood
4	EID	Lateral 14-03 Bow Slope	Buried membrane liner with cover & gravel armour	Sprinkler (pivot) & Flood
5	WID	Lateral 82-K North 'A'	Impervious Till-Low Side	Flood

EM-38 salinity surveys, using a 50 x 50 m grid, were conducted at each site in late April. Readings were taken with the instrument in the vertical mode. Temperature-corrected EM-38 data were converted to paste-equivalent electrical conductivity (EC_e) values according to the method of McKenzie et al. (1989). Grid EC_e values were then contoured using "Surfer" computer software to produce a 1:1875 scale salinity map for each site. EM-38 generated EC_e values were checked by sampling soil profiles at random locations throughout each grid. Samples were taken in 15 cm depth increments to a depth of 1.2 m and analyzed for saturation paste electrical conductivity (EC).

Five 50 x 50 m plots were then selected at each site based on the results of the EM-38 survey. Plot corners corresponded to grid points and were referenced to permanent benchmarks at each site.

Water-table wells were installed to a depth of 4.5 m in the center of each plot. Soils were sampled in 15 cm depth increments to a depth of 1.2 m during installation. Below 1.2 meters, samples were taken every meter or when there was a change in parent material. A small pit (50 cm x 50 cm x 75 cm deep) was excavated by each well to describe and sample soil profiles.

Water-table levels were monitored biweekly, except around canal turn on and shut down events when monitoring was done weekly. Dataloggers connected to automatic water level recorders and tipping bucket rain gauges were installed over one well at each site to continuously monitor water table fluctuation in response to irrigation and precipitation events.

Reclamation of salt-affected land units will be monitored by soil characterization and sampling, biannual EM-38 salinity surveys, and groundwater monitoring.

Soil Characterization and Sampling

The soils within each of the 50 x 50 m plots at each study site were inspected to a 1.8 m depth in the vicinity of each of the four plot corners and the plot center. Cores shall be obtained randomly from within a 1 m diameter circle having the plot corner as the centre.

Soils were sampled in the fall (during the period from October 1 to November 15) at depths of 0-0.3, 0.3-0.6, 0.6-0.9 and 0.9-1.2 m. Samples were analyzed in the laboratory for pH, ECe and SAR of the saturation paste extract. Particle-size distribution of initial soil samples were determined in the laboratory (Gee and Bauder 1986).

Soils at the corners and centre of each plot were described according to horizons, depth, effervescence, texture (manual), moisture conditions and parent material. Each soil profile was classified in accordance with the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987).

Soils were sampled prior to rehabilitation and shall be subsequently sampled every two years for at least six years, with samples obtained from similar locations at the same depth intervals as during initial characterization and shall be analyzed similarly in the laboratory. Changes in salinity levels over time shall be determined using a split-plot analysis of variance statistical model.

EM-38 Surveys

Changes in the spatial distribution of salinity shall be determined by performing biannual EM-38 grid surveys on a 10 x 20 m grid for representative affected areas. Biannual contour maps showing temperature-corrected, paste-equivalent ECe values shall also be prepared from EM-38 readings taken in both horizontal and vertical modes. A map at a scale of 1:10,000 showing the extent of land having ECe values greater than 4 dS m^{-1} and giving ECe contours at intervals of 2 dS m^{-1}, shall also be prepared biannually for at least six years for documentation of changes in the size and severity of affected areas.

Groundwater Monitoring

Water-table levels will be monitored biweekly from spring melt to freeze up, except during canal turn on and shut down periods when monitoring will be done weekly. Installation of piezometers and groundwater modelling will be done at the WID site and may be done at one other site.

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SUBSURFACE DRAINAGE VERSUS HIGH MOISTURE USE CROPPING FOR SALINE SEEP CONTROL IN EAST-CENTRAL ALBERTA: SALINITY STATUS AFTER THREE YEARS OF MONITORING (FALL 1988)

D. Mikalson[1]

INTRODUCTION

Results of two years of monitoring the relative effectiveness of subsurface drainage and high moisture use cropping (HMUC) as saline seep control alternatives in east-central Alberta is summarized by Harker et al. (1988). No significant differences in electrical conductivity (EC_e) or sodium absorption ratio (SAR) were found between treatments or between years. However, it was recognized that sufficient time had not elapsed to provide detailed conclusions and additional monitoring would be required.

This report includes data from a third (1988) cropping season and re-evaluates the soil salinity status. Soil samples were collected at the same field locations (Figure 1) and depth intervals and were analyzed by the same methods as described by Harker et al. (1988). These data were appended to the previous data file and were evaluated by similar graphical and statistical methods. SAR trends were generally similar to EC_e and are not shown or discussed.

RESULTS AND DISCUSSION

Average EC_e for the HMUC and subsurface drainage treatments (Table 1) show that although some fluctuation has occurred, EC_e means in the fall of 1988 are similar to fall 1985 levels for both treatments. Because initial salinity levels (1985) were higher in the subsurface drainage treatment, a ratio $EC_{86,87or88}/EC_{85}$) method was used to examine the change in salinity between treatments and over time. A nested ANOVA (replicate within treatment) design was used to test EC/EC_{85} between treatments and years for each depth increment. The replicates correspond with slope positions. No significant differences ($p = 0.05$) were found between treatments, years or interaction between year and replicate within treatment except that in the 0.3 to 0.6-m and 1.5 to 1.8-m depths a significant difference was evident between years.

As the statistical design indicated a replicate (slope position) within treatment difference in the upper profile depth increments, this aspect was examined in detail. Average EC_e by treatment and slope position for the 0 to 0.15-m soil depth shows higher initial salinity in the upslope subsurface drainage treatment compared to the upslope

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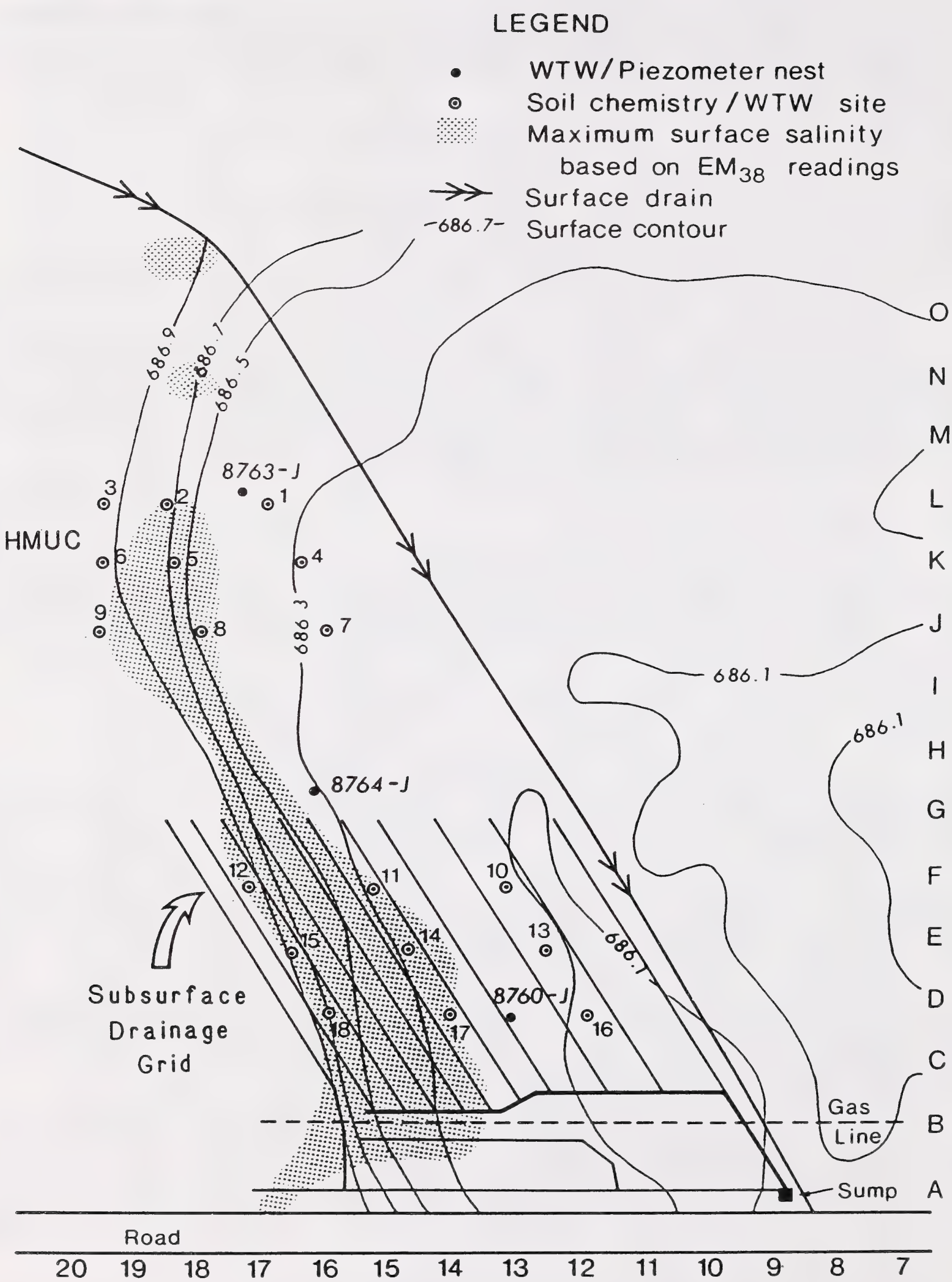

Figure 1. Location of maximum surface salinity, soil/groundwater monitoring sites, and subsurface drainage grid.

Table 1. Average soil electrical conductivity (EC_e) by depth under high moisture use cropping (HMUC) and subsurface drainage treatments in four years of monitoring at Viking FFF project.

Depth	Treatment	YEAR 1985	1986	1987	1988
		-----------------	$dS\ m^{-1}$	-----------------	
0 - 0.15 m	HMUC	8.4	6.8	8.1	7.3
	Subsurface drainage	12.5	8.9	11.1	12.4
0.15 - 0.30 m	HMUC	8.4	8.0	8.1	7.5
	Subsurface drainage	9.6	8.2	8.8	10.2
0.30 - 0.60 m	HMUC	8.1	7.0	8.2	8.4
	Subsurface drainage	8.4	8.0	8.5	8.5
0.60 - 0.90 m	HMUC	6.9	6.4	6.9	7.1
	Subsurface drainage	8.3	7.9	8.3	8.1
0.90 - 1.20 m	HMUC	6.1	6.0	6.5	5.9
	Subsurface drainage	8.6	8.0	8.3	8.2
1.20 - 1.50 m	HMUC	6.0	5.7	5.9	5.5
	Subsurface drainage	8.7	7.8	8.1	8.4
1.50 - 1.80 m	HMUC	5.8	5.4	6.1	5.6
	Subsurface drainage	8.4	7.7	8.4	8.4

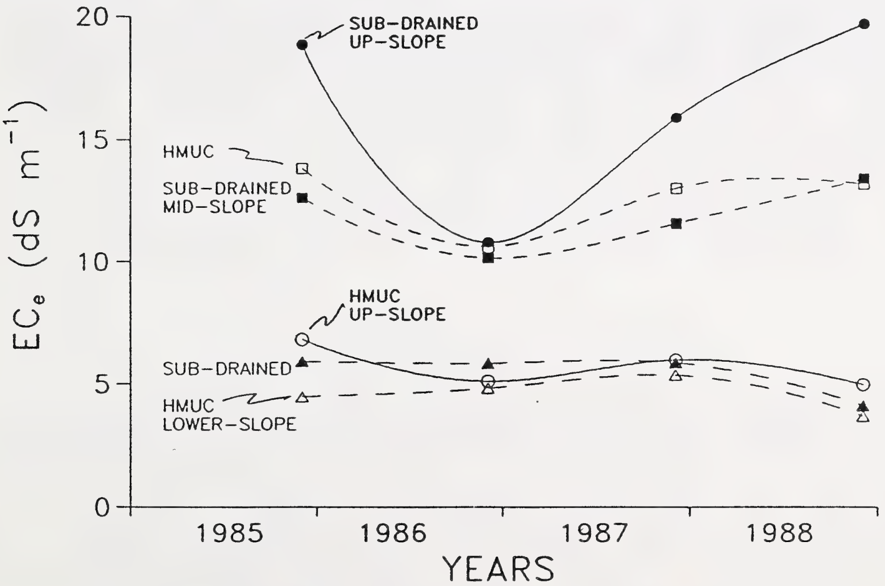

Figure 2. Average soil electrical conductivity (EC_e) in the 0-0.15 m depth by slope position for subsurface drainage and HMUC treatments.

HMUC treatment and similar salinity between treatments in the mid- and lower-slope positions (Figure 2). In the upslope position, along the toe of the topographic rise, the subsurface drainage treatment improved initially (1986) but resalinized to initial (1985) levels in the last two years. The upslope HMUC treatment has improved slightly over this time period. Salinity of the subsurface drainage and HMUC treatments have followed similar trends for the mid- and lower-slope positions.

SUMMARY AND CONCLUSIONS

These results are similar to the conclusions of Harker et al. (1988). Significant differences between treatments or years were not evident. Examination of replicates within treatments suggests that a difference between treatments may be developing in the upslope position, along the toe of the topographic rise, however, further monitoring would be required to establish any long-term conclusions.

Resalinization of the upslope subsurface drainage treatment suggests that historic factors causing salinization remain active. It may be beneficial to enhance infiltration and leaching from precipitation by using cultural practices such as shallow tillage to create a loose surface and reduce runoff, incorporation of straw or manure and perhaps seeding nonproductive areas to salt-tolerant perennial grasses.

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GROUNDWATER-FLOW MODELING OF DEEP INTERCEPTOR AND GRID DRAINAGE FOR CANAL SEEPAGE CONTROL

D. Millette[1], G. D. Buckland[2], W. R. Galatiuk[3] and C. Madramootoo[4]

INTRODUCTION

The presence of shallow water table and the gradual buildup of saline soil downslope of irrigation canals has focused attention on the need for canal seepage control. Deep-interceptor drains are commonly used to control seepage from large irrigation canals. Typically, 150- to 300-mm diameter clay tile or perforated-polyethylene tubing is placed adjacent to the canal at depths varying from 2 to 4 m below ground. A gravel chimney is placed above the drain to prevent the seepage from bridging over the drain. Provided drainage problems are caused primarily by canal seepage, correct placement of the deep-interceptor drain should reduce the downslope water-table depth to the depth of the drain. However, if a shallow downslope water table is partially the result of natural groundwater, grid drainage may be more beneficial.

Grid drainage involves placing a series of parallel, regularly spaced 100-mm diameter flexible, corrugated, polyethylene tubing throughout the saline/waterlogged areas downslope of the canal. Drain depth varies from 1.0 to 1.8 m. Besides intercepting both canal seepage and natural groundwater, grid drainage may have the added advantage of providing a sink for leaching water, thereby accelerating reclamation.

While these two methods are known to be effective in controlling seepage, their relative effectiveness to reclaim saline soils under southern Alberta conditions has not been documented. A study was therefore initiated in the spring of 1987 to determine the relative effectiveness of deep interceptor and grid drains to control canal and natural-groundwater seepage and reclaim saline/waterlogged soils. This report outlines results of groundwater-flow modeling which was conducted at four sites along the St. Mary River Irrigation District Main Canal where either grid or deep interceptor drains were installed to control canal seepage.

MATERIALS AND METHODS

Characteristics of the four sites which were selected for detailed groundwater instrumentation and mathematical-flow modeling are given

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in Table 1. At each site transects of 10 to 14 water-table wells and 5 to 7 piezometer nests were installed. Each transect extended from about 200 m upslope of the canal to 600 m downslope. Groundwater levels were measured weekly or every second week from December 1987 to February 1989. The monitoring was designed to determine the nature of the canal seepage and the groundwater regime and to determine how well the existing drains were functioning. Single-well response tests (Hvorslev 1951) were performed on piezometers to determine the in-situ hydraulic conductivity of different geologic layers.

Table 1. Description of the experimental sites.

Site and Location	Type of Drainage[+]	Predominant Surficial Geology	Topography
Taber-I1 W½ 14-9-17-4	Deep Inter. (0.6 m)	Shallow fluvial (1.0-3.0 m) over bedrock	Nearly level (2.0%)
Taber-I2 W½ 7-9-16-4	Deep Inter. (0.8-2.3 m)	Deep till (35 m) Scattered pockets of fluvial material	Level (0.3-0.5%)
Bow Island-G1 NE¼ 9-9-11-4	Grid (-0.4-0.0 m)	Till (5.0-6.0 m) over coal (1.5 m) or bedrock; pockets of fluv. or lac. (1-2 m) over till	Level (0.5%)
Bow Island-G3 SW¼ 15-9-11-4	Grid (-1.0-0.0 m)	Lacustrine (0.0-2.0 m) over till (2.0-4.0 m) over bedrock over coal.	Nearly level (0.6%)

[+] Values in brackets give depth of first drain below canal invert.

The groundwater-flow modeling was designed to compare the relative effectiveness of deep-interceptor drainage and grid drainage under identical hydrogeological conditions. Simulations were carried out using the modular three-dimensional finite-difference groundwater-flow model (MODFLOW) developed by McDonald and Harbaugh (1988). The model allows for recharge, evapotranspiration, rivers (canals), surface and subsurface drains, constant-head sources and wells. Input data required for each site included ground elevation, thickness of each geological unit and horizontal and vertical hydraulic conductivities.

The model was calibrated at each site by adjusting the model parameters in a trial and error process until the results of the simulations were in general agreement with representative groundwater elevations measured during the summer of 1988. Simulated hydraulic heads were usually within 20 cm of the measured heads. The calibration was then checked by running the model using data representative

of winter conditions. Simulated and measured heads were again within about 20 cm. Once calibrated, additional simulations were generated by varying the type of drainage system (interceptor, grid or none) and the amount or irrigation recharge. In all, five simulations were generated: (1) deep interceptor drainage, no recharge; (2) grid drainage, no recharge; (3) no drainage, no recharge; (4) interceptor drainage, recharge; and (5) grid drainage, recharge. Note that at each site one of the above simulations was performed during the calibration step. Further details on the groundwater-flow modeling are given by Millette et al. (1989).

RESULTS AND DISCUSSION

Figure 1 gives results of groundwater simulations for deep interceptor, grid and no drainage at the four study sites. Simulations are for the existing land management, no recharge - that is, a leaching fraction has not been added to allow for the leaching of salts.

At site I1, the effect of both types of drainage on the water table (relative to no drainage) is limited (Figure 1a). The interceptor drain would lower the water table below the "no drain" level for a distance of only 200 m downslope of the canal. Grid drainage would lower the water table throughout the transect but to a lesser degree than the deep interceptor drain within the first 200 m. At downslope distances greater than 200 m, however, grid drainage would lower the water table to a greater extent than deep interceptor drainage. The relatively poor performance of the deep interceptor and grid drains at this site results from from bedrock which underlies the site at depths of 1 to 2 m. This bedrock limits the depth of drain installation and is also a source of natural groundwater discharge. The predominant area of groundwater discharge occurs in the lower portion (200 to 400 m) of the transect (Millette et al. 1989). It is in this lower portion of the transect that the grid drains outperform the deep interceptor drain.

At site I2, the deep interceptor drain and the grid drains provide approximately equal and adequate control of the water table (Figure 1b). The good performance of two types of drainage is because downslope salinization is mainly associated with canal seepage.

At site G1 a deep-interceptor drain would lower the water table only within 50 m of the canal (Figure 1c) while grid drainage would lower the water table throughout the monitored transect. Similar results were observed at site G3 (Figure 1d) although the influence of the deep interceptor extends to about 200 m. Both sites G1 and G3 have similar hydrogeology: 5 to 6 m thick lacustrine or till materials overly a coal seam which in turn overlies bedrock. Groundwater in the coal seam is under pressure and there are strong upward gradients towards the water table. This coal seam is largely responsible for salinization at these two sites and is the main reason for the poor performance of the interceptor drain. The interceptor drain would perform better at site G3, compared to site G2, because the coal seam is capped by a thin layer of bedrock which restricts upward movement of groundwater.

Simulations were done using recharge of 0.26 mm day^{-1} to simulate leaching which would enhance reclamation of the soils. The rate of 0.26 mm day^{-1} represents the steady-state rate of recharge

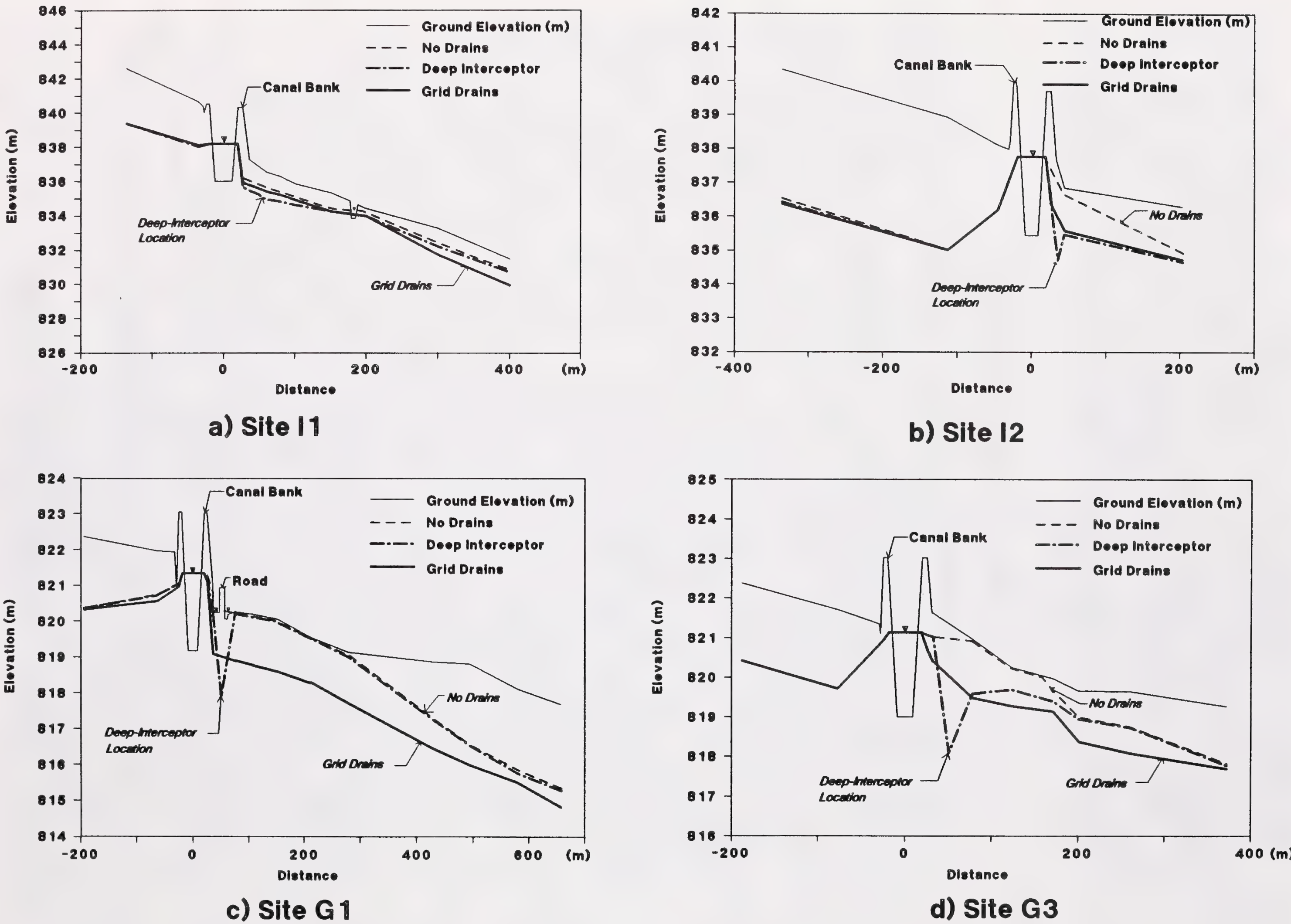

Fig. 1. Simulated water-table response under existing land management.

required to maintain low salinity under an irrigated alfalfa crop (Robertson 1988). Results (Figure 2) indicate that at all sites the grid drains would provide better water table control than the interceptor drain. This likely occurs because the geologic materials have insufficient natural internal drainage to allow for leaching.

CONCLUSIONS

Mathematical modeling of canal seepage control using deep interceptor and grid drainage shows that when natural groundwater partially contributes to seepage affected soils, grid drainage offers better water-table control. Where affected lands result mainly from canal seepage, grid drainage and deep interceptor drainage are equally effective. Simulations conducted using a leaching fraction indicated that grid drainage will provide better water table control than deep interceptor drainage. Thus, grid drainage offers greater potential for reclamation of seepage-affected soils than does interceptor drainage.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Farming for the Future Council of Alberta and Alberta Agriculture.

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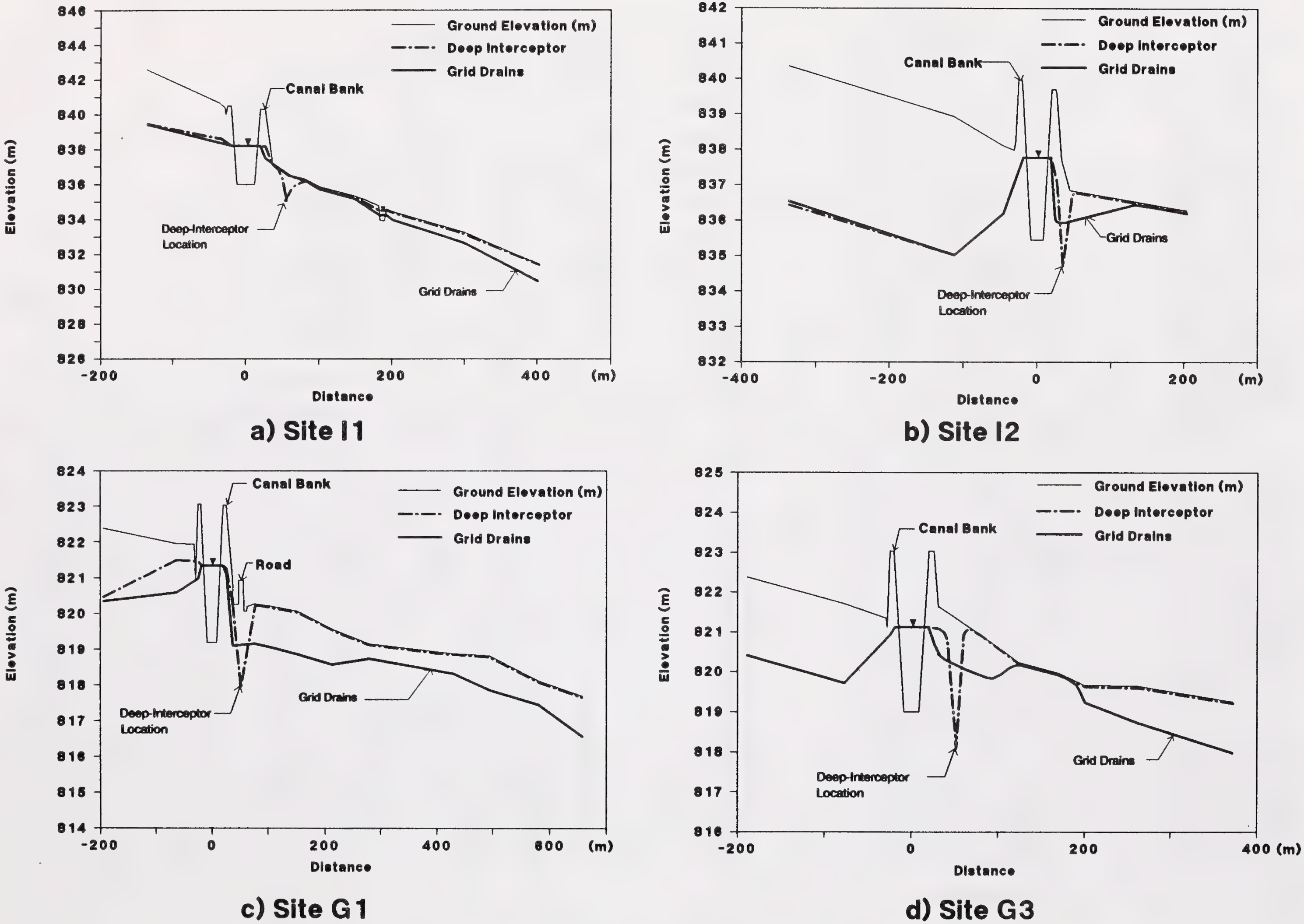

Fig. 2. Simulated water-table response to irrigation recharge.

WALKER TWELVE-YEAR APPLIED RESEARCH REPORT

D. Mikalson[1]

INTRODUCTION

In 1975, Alberta Agriculture initiated an evaluation of shallow subsurface drainage at several sites in southern Alberta. One of these sites located near Magrath was studied in detail. This site had been out of production for 20 years due to high watertable and salinity problems associated with upward gradients from the underlying sand and gravel material (Paterson and Harker 1980). Flexible drainage tubing was installed within the underlying coarse material at depths ranging from 1.1 to 1.5 metres. Drain lateral lines were spaced at 15 m, except for a test area where one lateral was omitted to provide a comparison of 15 and 30 m spacings. In the spring of 1977, a portion of this test area was monitored and reclamation activities were initiated.

After two years of barley production, leaching provided by flood irrigation and seasonal precipitation had substantially lowered the salinity in the surface soil (0-0.30 m). The 15 and 30 meter spacings were found to be equally effective in controlling the watertable at or below drain-line depth due to the influence of the sand and gravel layer.

The question remained, however, whether normal irrigation could maintain or enhance the reclamation achieved by initial leaching. This study was initiated to monitor long term reclamation after installation of subsurface drainage under normal flood irrigation and farm management practices.

METHODS

In this study, the sampling grid (Bennett et al. 1982) was reduced to twenty mid-spacing sites (Figure 1). These were sampled in the fall of 1979, 1980, 1982, 1984, 1986 and 1988 and were analyzed to determine electrical conductivity (ECe), soluble cations and sodium absorption ratio (SAR) from saturated soil extracts.

After four years of irrigated grain production, the site was seeded to alfalfa in 1981 and has remained in production of alfalfa and grass hay. During this period, the site was subject to the land-owner's normal flood irrigation practices. Generally, grains were irrigated once and alfalfa twice each season.

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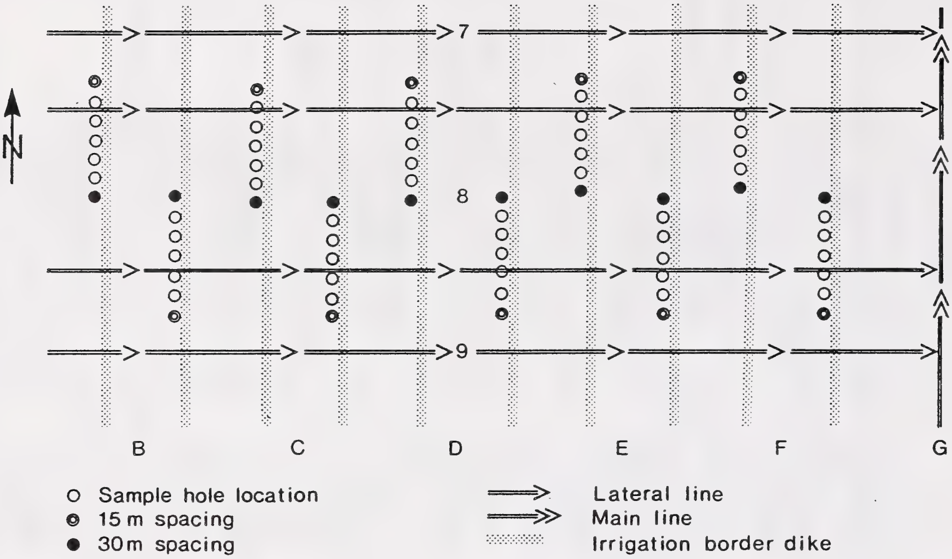

Figure 1. Location of mid-spacing sampling sites with original investigation area

RESULTS AND DISCUSSION

15 vs 30 m Spacing

Nested multiway ANOVA crossed with time indicated that mean salinity ratio's ($ECe_{f77....f88}/EC_{s77}$) differed between sampling years for all depths, but did not differ between spacings for any depth increment. Data for the 15 and 30 m spacings were therefore grouped and single factor ANOVA and multiple range tests were compiled to examine differences in ECe response between sampling years for each depth increment. SAR trends were similar to ECe and are not further discussed.

Reclamation Over Time

Mean ECe and reclamation ratio values are shown by depth in Table 1. Salinity ratio's were significantly different ($p=0.05$) between sampling periods for the 0-0.15, 0.15-0.30, and 0.30-0.45 m depths. These ratio's did not differ between sampling years for mid-profile depths (0.45-1.2 m) but differed significantly in the 1.2 to 1.5 m-depth interval.

Table 1. Salinity response ratio* and mean ECe over a twelve year period since the installation of subsurface drainage at the Magrath site.

Depth (m)	SP77	FA77	FA78	FA79	FA80	FA82	FA84	FA86	FA88
	1.00*	0.85a	0.41b	0.54b	0.44b	0.42b	0.29b	0.47b	1.15a
0.00 - 0.15	7.34+	6.26	2.92	4.06	2.84	2.79	1.94	3.28	8.04
	1.00	1.02a	0.81abc	0.94ab	0.65bcd	0.48d	0.54cd	0.61cd	1.01a
0.15 - 0.30	8.07	7.80	6.06	7.30	4.71	3.59	4.10	4.69	7.55
	1.00	1.09ab	0.91abc	1.21a	0.88abc	0.68c	0.80bc	0.89abc	0.98abc
0.30 - 0.45	7.22	7.75	6.48	8.67	6.05	4.74	5.49	6.24	6.66
0.45 - 0.60	6.58	7.44	6.04	8.26	6.29	6.05	6.56	6.61	6.00
0.60 - 0.75	6.15	6.84	5.52	7.36	6.51	7.01	7.38	6.50	5.40
0.75 - 0.90	5.72	6.29	5.29	6.47	6.13	6.57	6.94	5.57	4.73
0.90 - 1.05	5.55	5.45	4.85	5.68	5.72	5.61	5.55	5.03	4.46
1.05 - 1.20	4.79	4.78	4.26	5.36	5.61	4.61	4.74	4.42	4.18
	1.00	1.11ab	0.94b	1.38a	1.21ab	0.97b	0.96b	0.89b	0.92b
1.20 - 1.50	4.36	4.50	3.93	5.53	4.83	3.89	3.73	3.66	3.81

Within each depth, mean values of ECe Ratio followed by the same letter do not differ significantly (LSDMOD p=0.05, SPSS®).

Mean ECe for these upper profile depths are plotted by sampling period in Figure 2. During two years of initial leaching (1977 and 1978), ECe improved by 60% in the 0-0.15 m depth to 2.9 dS m^{-1}. Mean ECe increased slightly in 1979 and improved to 1.9 dS m^{-1} five years later. Since that time substantial resalinization has occurred and ECe has increased to 8.0 dS m^{-1} (Fig. 2).

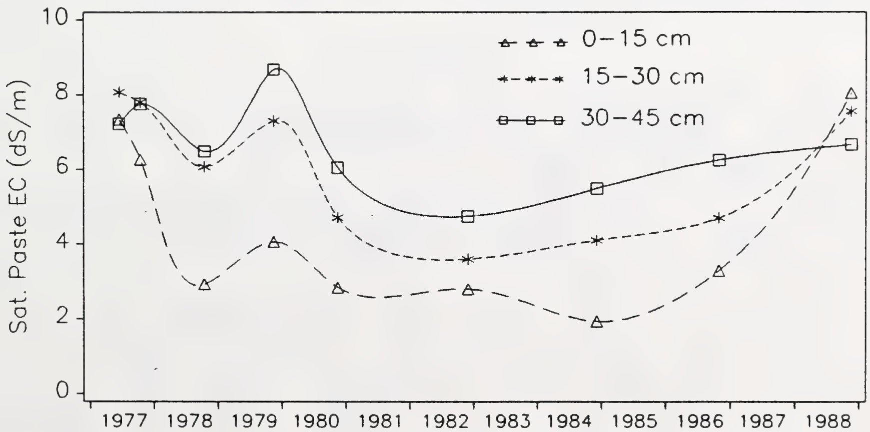

Figure 2 Mean electrical conductivity (ECe) by sampling period for upper soil profile.

In the 0.15 to 0.30 m-depth, ECe improved by 25% during two years of initial leaching. After an additional four years (1982) of normal irrigation and precipitation, these levels were further reduced to 3.6 dS m^{-1}. This represents a reduction of 56% from initial levels. These levels were similar or slightly increased through 1984 and 1986 but have since resalinized to 7.55 dS m^{-1} (fall 1988). Similarly, the 0.30 to 0.45 m-depth reclaimed slightly (<10%) during initial leaching and further improved under normal activities over the next four years. By 1982, mean ECe in the 0.30 to 0.45 m-depth had improved to 4.7 dS m^{-1} (34% of initial ECe). However, as in the surface sampling interval, salinity in these depths has resalinized to pre-leaching levels (Fig. 2).

Resalinization observed at all depths in 1979 (Table 1) may have been linked to restricted flow from the mainline outlet which was damaged during installation of a gas pipeline. In the 1.2-1.5 m depth, ECe was substantially higher than the previous fall. After the outlet was repaired, soil ECe improved to previous levels.

CONCLUSIONS

Soil salinity levels reduced by initial leaching were maintained and in some years were further reduced under normal flood irrigation management after installation of subsurface drainage. However, in recent years, resalinization has been evident in the upper profile and after twelve years of monitoring, soil salinity is similar to initial pre-leaching levels. Although the recent resalinization is likely related to current irrigation and salinity management at this site, it may be an indication of problems with the subsurface drainage system or outlet. Resalinization suggests a need to examine and correct any system problems followed by intensive irrigations to leach salts. Reclamation management should include periodic measurement of soil chemistry and irrigation management that provides sufficient available moisture and a leaching requirement for salinity control (Rhoades 1982). Several devices are available that provide quick field monitoring of salinity perhaps these could be incorporated into reclamation management.

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LEACHING OF HIGHLY SALINE-SODIC SOILS IN SOUTHERN ALBERTA - A LABORATORY STUDY

D. Mikalson[1]

INTRODUCTION

Soil salinity is caused by the accumulation of soluble salts in the soil profile when excess soil moisture from shallow groundwater is removed by evaporation and consumptive use. Reclamation of these soils may be accomplished by first controlling the excess water source and/or providing adequate drainage to lower the water table followed by leaching of excess soil salts as water from irrigation and precipitation drain through the soil.

In southern Alberta, most soils with serious salt problems are saline-sodic and contain precipitated gypsum and lime (Sommerfeldt et al. 1988). Studies have shown that subsurface drainage combined with irrigation can be effective in reclaiming these soils. However, areas of high (EC>12 dS m^{-1}) and very high (EC>40 dS m^{-1}) salinity and sodicity are frequently encountered and there is a need to examine the reclamation feasibility and leaching characteristics of these soils. Therefore, a laboratory study was conducted to examine the relationship between water movement and salt removal and to determine the depth of water and time required to achieve soil reclamation.

MATERIALS AND METHODS

Soil cores were extracted from a severe saline-sodic seep area located 50 km east of Lethbridge, Alberta. Three sampling sites (C2, E2, G2) were located in a lower slope (discharge zone) and three (C4, E4, G4) were located in a higher slope position (recharge/transitional zone). Two cores were extracted at each site, one for leaching and one to determine pre-leaching salinity distribution. Soils were classified as Brown Solodized Solonetz developed on a fluvial-lacustrine veneer of sandy clay loam to clay overlying clay loam till (Duchess and Rolward series).

Leaching was done by continuously ponding 10 mm of city tap water on the surface of the soil column. This water is of good quality and is similar to irrigation water used in the region. For two cores, C4 and E4, rapid flow necessitated interrupted leaching periods which would have briefly simulated intermittent rather than continuous leaching. Leaching of five cores was terminated when the EC of the drainage effluent (EC_L) stabilized between 2 and 4 dS m^{-1}. For the remaining core (E2) leaching was terminated after 1 yr although EC_L was still 23 dS m^{-1}.

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Leached and unleached soil cores were sampled in 5 cm increments and were analyzed to determine electrical conductivity (ECe), major cations and sodium absorption ratio (SAR) of the saturated paste extract. Saturated hydraulic conductivity was calculated for each sampling interval during leaching, assuming constant head conditions.

RESULTS AND DISCUSSION

Salinity Reclamation

In all cases, ECe for the leached soils was reduced <4 dS m^{-1} near the soil surface. The ECe of cores C2 and G2 were reduced throughout the 0.5-m profile. Core E2 retained some salts in the lower profile because leaching was stopped after 1 yr.

Similar to ECe, SAR levels were reduced by leaching with low salinity water, indicating that sufficient precipitated gypsum, lime and soluble calcium were available for exchange with Na during leaching.

Leaching Relationship

Hoffman (1980) described the equation $(C/C_O)*(D_L/D_S) = k$ where C and C_O are the effluent salt concentration and initial salt concentration, respectively, D_L and D_S are the depth of leaching water applied and the depth of soil, respectively, and k is an empirical constant (0.3 for CL soils). Data comparing the relative remaining salinity (C/C_O) with the ratio of depth of water applied to depth of soil (D_L/D_S) for the six cores is shown in Figure 1. The leaching constant, k, for individual cores ranged from 0.17 to 0.37 (Table 1) with an average k of 0.25 for all cores (for $D_L/D_S \geq 2.0$). Thus, the application of a depth of leaching water equal to the depth of soil ($D_L/D_S = 1.0$) could be expected to reduce initial salinity levels by 63 to 83%, with an average reduction of about 75%. The initial level of salinity or the possible presence of precipitated salts does not appear to influence the depth of leaching water required.

Time Required

Actual leaching times (Table 1) ranged from 3.5 to 359 d which includes differences in total depth of water applied, final ECe achieved and periods of interrupted leaching in two cores. To standardize the leaching comparison, the time required to apply one depth of water with continuous ponding was determined from the data for cores C2, G2, C4, E4 and G4 and was extrapolated from available data for core E2 (Table 1). The time required to pass one depth of water through these soils ranged from 1.6 d to an estimated 460 d (Table 1). After leaching with one depth of water, soils might retain some salinity within the upper soil profile but would have lower salinity levels near the soil surface.

Hydraulic Conductivity

Hydraulic conductivity values were calculated for each effluent sampling interval and are shown in Figure 2. Mean hydraulic conductivity ranged from 0.001 to 0.59 m d^{-1} (Table 1). In four of the six cores hydraulic conductivity remained relatively constant during

leaching (cores C2, C4, E4 and G4). While in the remaining cores (E2 and G2) about a 10-fold decrease in hydraulic conductivity occurred during leaching. This may indicate that some soil dispersion and sealing occurred.

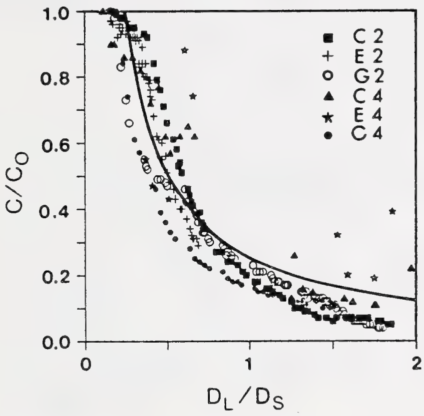

Figure 1. Relative salinity reduction (C/C_0) versus water application (D_L/D_S) of leached soil cores.

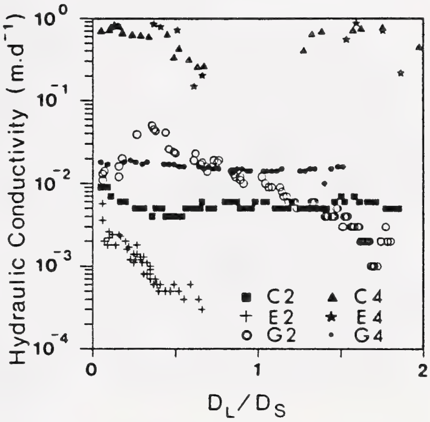

Figure 2. Hydraulic Conductivity versus water application (D_L/D_S) of leached soil cores.

Leaching with Normal Irrigation

Reclamation of these soils does not appear to be influenced by the initial soil salinity or sodicity levels. The primary limitation to leaching these soils in the field will be the low infiltration and hydraulic conductivity combined with the irrigation management practices common in southern Alberta. Currently, 78% of the irrigated land is under sprinkler irrigation (Alberta Agriculture, unpublished data). As previous studies have shown that sprinkler irrigation does not fill the soil reserve to field capacity it is unlikely that normal sprinkler irrigation would provide sufficient leaching to reclaim saline-sodic soils. Further, sprinkler application rates may be in excess of the infiltration rate/hydraulic conductivity of the soil. This would also result in limited leaching of the soil. For soils with low hydraulic conductivity, such as that observed in Core E2, leaching might be achieved with continuous ponding. Where sprinkler irrigation is contemplated, unless cultural or other practices can significantly enhance the infiltration/hydraulic conductivity rate of the soil, reclamation times will be impractical.

CONCLUSIONS

This study has shown that soils with high and very high salinity and sodicity can be reclaimed by leaching with good quality water and has further shown that the primary limitation to reclamation in the field will not be initial salinity or depth of leaching water but rather will be low infiltration/conductivity rates and the length of time required.

Table 1. Summary of experimental leaching data

	Core Number					
	C2	E2	G2	C4+	E4+	G4
Soil depth (D_S, mm)	510	460	540	490	450	540
Initial effluent concentration ($EC_L = C_0$, dS m^{-1})	76	79	62	25	13	41
Final effluent concentration (EC_L, dS m^{-1})	3.7	22.7	2.5	4.4	2.4	4.4
Total water applied (mm)	940	320	970	1760	2070	810
Actual days of leaching	157	359	127	4.9	3.5	50
Leaching constant (k)	0.21	0.26	0.20	0.26	0.37	0.17
Hydraulic conductivity (m d^{-1})	0.006	0.001	0.008	0.3555	0.590	0.015
Days of leaching required for D_L/D_S = 1 (days)	82	460#	26	1.6	1.6	32
Estimated EC at (D_L/D_S (dS m^{-1})	14	13#	19	7	5	7

\# Leaching of Core E2 was terminated at D_L/D_S=0.7. Values given are from a best-fit projection.

\+ Leaching of Cores C4 and E4 was interrupted several times. Results will reflect periods of intermittent ponding.

ACKNOWLEDGMENTS

The assistance of G. Greenlee for soil classification interpretation is appreciated.

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GROUNDWATER CONTRIBUTION TO CONSUMPTIVE USE

Bill Read[1]

INTRODUCTION

With increasing demands being placed on our water resources, the availability of groundwater as a moisture source for crop use is of significance. A consequence of shallow groundwater use, however, can be soil salinization. The intent of this multi-year project was to quantify the groundwater contribution to crop use and to measure the movement of salt. The interaction and effects of soil texture, cropping, groundwater quality, and irrigation on groundwater movement were also evaluated. This report is a summary of the entire 9 years of this study and presents cummulative groundwater contribution and soil salinity values.

METHOD

Thirty-two, two metre long columns of 380 mm diameter PVC pipe were filled with non-saline topsoil. Half of the columns were filled with coarse textured soil and the other half with a fine textured soil. The columns were placed in a 2 m deep wood cribbed pit. Water tables were established in the columns from Mariotte syphons which maintained a constant watertable at either 1.2 or 1.8 metres below the soil surface. Half of the columns received non-saline water and the other half had saline water as the groundwater supply. Half of the columns were cropped to barley and half were fallowed. The columns received surface water applications if and when soil tensions at the 40 cm depth reached 500 millibars. Spring and fall soil moisture sampling along with the monitoring of rainfall, irrigation and groundwater use permitted a calculation of the water balance in each column. The water withdrawal from the Mariotte syphon was considered to be the groundwater contribution to consumptive use. Soil salinity was measured by salinity sensors at 40 and 90 cm depths in each column.

RESULTS

The effect which the four variables, crop situation, soil texture, irrigation regime and water quality have on crop consumptive use and salt movement will be briefly discussed.

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Crop Situation

Extraction of soil moisture by a crop increases the soil moisture tension gradient in the root zone. In response to this gradient, shallow groundwater can move upward by capillary action to reduce this moisture gradient. Upward movement of groundwater under fallow conditions is primarily a function of evaporation and is usually less than under cropped conditions. Accordingly, mean seasonal groundwater use by the cropped columns from a 1.2 m watertable was 323 mm as compared to 87 mm in the fallow treatments.

Groundwater use by the cropped columns with a 1.8 m watertable was 105 mm. The contribution of groundwater from this depth in the fallow treatments was not sufficient to contribute to consumptive use and in this case can be considered nil.

Soil Texture

Capillary rise theoretically can move groundwater to a greater height in a fine textured material than in a coarse one. Consistent with this, upward transport from a depth of 1.2 m in treatments containing fine textured soil was 197 mm as compared to 181 mm in the coarser soil. From 1.8 m, groundwater contributions in fine textured treatments was 128 mm, and 82 mm in the coarse textured treatments. Whether cropped or fallow, the soil textural influence on upward groundwater movement was the same.

The soils used in this study were from different textural groups, but particle size analysis indicated a textural likeness. This may account for the similarity in upward water transport between textural groups from the 1.2 m depth. In the cropped treatments, the rooting depth may also serve to negate any textural influence on upward water transport. Barley has a potential rooting depth of 1.4 m and may, as a result, extract moisture directly from a 1.2 m watertable, thereby diminishing the effect of soil texture.

Irrigation Regime

In each textural group, one half of the columns received irrigation water when tensiometers at the 40 cm depth indicated tensions of 500 mb or greater. The absence of crop moisture extraction in the fallow columns did not result in sufficient soil moisture tension to initiate irrigation at any time throughout the season. There was, therefore, no distinction between irrigated and non-irrigated fallow treatments with regard to groundwater contributions.

Regression analysis of irrigation applications versus groundwater contributions indicated a high correlation between these two variables; that is, the higher the irrigation application the lower the groundwater contribution ($r = -0.95$). There was also a significant relationship evident when moisture applications, rainfall and irrigation, were totalled and regressed against groundwater contributions ($r = -0.99$). Again the higher the amount of irrigation and rainfall applied, the lower the groundwater contribution. When rainfall alone is compared with the groundwater contributions, the relationship is low ($r = -0.38$). Rainfall was usually received in quantities either used directly by the crop, or stored in the upper portion of the root zone. Irrigation, on the other hand, was 50 mm per application, an amount often sufficient (especially

when combined with rainfall) to affect the tension of soil water in the vicinity of a 1.2 m watertable, as indicated by the 90 cm tensiometer; this can ultimately cause a reduction in the withdrawal of water from the watertable. As such, groundwater contributions in the irrigated, and non-irrigated cropped treatments were 208 mm and 215 mm respectively.

Drought conditions were experienced in 1986 and 1988 when only 154 mm and 135 mm of rain were received. As a result, root zone moisture conditions were in a deficit situation for much of the growing season during these years. Consequently, applications of irrigation water were used almost entirely by the crop and did not reach the region of the watertable. The irrigation applications during these drought periods did not affect the tension of soil water in the vicinity of the watertable to the extent this occured in non-drought years. Therefore, the averaging of groundwater contribution data, drought and non-drought years included, may account for the similarity in groundwater contributions in the irrigated and non-irrigated cropped treatments.

It was expected that the volume of groundwater used would be reduced by the volume of irrigation water applied to the crop. The extent to which this occurred was much less than expected. The similarity between irrigated and non-irrigated groundwater contributions can be further explained if crop growth is considered. The treatments receiving irrigation water produced a more lush crop (mean straw weight 96.3 g) as compared to the non-irrigated treatments (mean straw weight 61.2 g). The more vigorous stand appeared to require water in excess of the irrigation applications. This may have placed an increased demand on the groundwater source in the irrigated treatments and may have resulted in increased groundwater consumption.

Groundwater Quality

The saline groundwater used in this study had an electrical conductivity ranging from 5.0 to 6.6 dS/m. It was expected that this water would result in a lower contribution to consumptive use than the non-saline groundwater (EC 0.4 dS/m). This was not the case. Contributions of saline groundwater in all treatments were 138 mm, slightly higher than the non-saline contribution of 134 mm. In the fallow treatments, saline groundwater use was again higher at 51 mm as compared to 47 mm in the non-saline treatments. In the cropped columns the trend was reversed, but only marginally, as groundwater use in the non-saline treatments exceeded those in the saline treatments by only 6%. While these differences in groundwater use are representative of the actual use, they are not statistically significant and may simply be random variations.

It is likely that the use of saline groundwater with a higher electrical conductivity would result in a lower contribution to consumptive use. Also, the cropping of a less salt tolerant crop in place of barley which was used in this experiment, may further differentiate between saline and non-saline groundwater use. It should be noted that the groundwater supplied was not the sole source of water provided to the crop. Rainfall and good quality irrigation water were also available and these sources may temper the emphasis placed on the saline groundwater by the crop.

Crop Situation

Cropping appeared to influence soil salinity development. Increases in salinity levels in the cropped treatments at all depths, except in the surface soil, were approximately double those found in the fallow treatments. At the 0 - 25 cm depth though, increases in salinity in the fallow treatments exceeded those in the cropped treatments by a factor of three. Groundwater contributions in the cropped columns were 4.5 times those occurring in the fallow columns and are largely responsible for the increase in upward salt movement. It is likely that a deeper groundwater table would not influence salinity development to such a large extent. As discussed previously, a 1.2 m watertable can supply 67% more water than that from a 1.8 m depth. Rainfall and irrigation in the cropped columns were over double that received in the fallow treatments, providing a degree of leaching and resulting in a lower salinity level in the surface soils.

Soil Texture

Salinity development was also affected by soil texture. Increases in salinity levels in the coarse textured treatments exceeded those in the finer textured treatments at all depths by 44 to 62 percent. This difference between treatments may be due in part to a 23 percent larger groundwater contribution and hence increased salt contribution in the coarse textured columns.

Groundwater Quality

As expected, increases in soil salinity were significantly higher in the columns fed with saline groundwater than in the non-saline treatments. The changes in salinity levels increased with depth, in fact at the 100 - 120 cm depth increment, soil salinity increases were 90 percent higher in the saline treatments than in the non-saline ones. In the surface soil, the saline groundwater did not influence the degree of salinization to the same extent as it did in the proximity of the water table, however, increases in salt levels were still 21 percent higher at the 0 - 25 cm depth as compared to the non-saline treatments. The volume of groundwater contributions in the saline and non-saline treatments were similar as were the amounts of surface water received.

Irrigation Regime

Surface applications of irrigation and rainfall in the irrigated (cropped) treatments were more than double those in the non-irrigated (cropped) treatments receiving rainfall alone. This volume of water was sufficient to limit the increases in root zone salinity development when compared with the non-irrigated treatments. This occurred either by the direct leaching of salts or by reducing the upward movement of groundwater required to meet crop needs. At all depth increments, increases in salinity levels were smallest in the irrigated treatments. In the surface soil where irrigation-initiated leaching took place, increases in salinity levels were 67% less than in non-irrigated treatments. Groundwater contributions in both treatments were essentially the same.

SUMMARY

1. The groundwater contribution to consumptive use by a barley crop, from a 1.2 m watertable, was 323 mm or 41% of total use. From a 1.8 m watertable, the groundwater contribution was 105 mm or 23% of total use, a 67% reduction.
2. Cropping of barley increased the groundwater use from a 1.2 m depth by 3.7 times over that found in a fallow situation.
3. The upward movement of water form a 1.2 m depth in a fine textured soil was 8% higher than in a coarse textured soil. The groundwater contribution from a 1.8 m depth was 64% higher in a fine textured material than in a coarse one. Soil textural influence on upward water movement is lessened as the depth to the watertable decreases or as the rooting depth of a crop increases.
4. Groundwater contributions of non-saline and moderately saline water were very similar (138 mm and 134 mm respectively). It appears that groundwater with an electrical conductivity of 5.0 - 6.6 dS/m does not affect the water use by barley.
5. Light, frequent applications of irrigation water did not significantly lessen the demand on the groundwater contribution to crop consumptive use.
6. Cropping increased the development of root zone salinity by a factor of two, except in surface soils (0 - 25 cm) where salinity levels increased under fallow conditions threefold.
7. Soil texture affected salinity development. Increases in salinity throughout the root zone in coarse textured soil were greater than in a finer textured material; on the average by 56%.
8. The influence of saline groundwater on soil salinity development increases as the distance from the source decreases. Saline groundwater increased salinity by 90% over non-saline groundwater in the region near the water table and by 21% in the surface soil.
9. Controlled applications of irrigation water reduced salinity development at the 0 - 25 cm depth by 67% compared to non-irrigated soils. This influence was reduced with soil depth.

A CONSERVATION TILLAGE DEMONSTRATION IN THE M.D. OF PROVOST

Thomas L. Jensen[1] and Gary McGregor[2]

INTRODUCTION

A conservation tillage demonstration was began in 1986 to increase awareness of conservation tillage practices in the M.D. of Provost. The demonstration is a joint project of the M.D. of Provost Agricultural Service Board, the District Agriculturist (A. Whiting), Mr. Harold Paulgaard and the above noted authors. The project is planned to run for five years and will conclude in the fall of 1990.

METHOD

The study was designed as a demonstration for local awareness but yield sampling is conducted in a manner so that the demonstration treatments can be compared using the students T-test.

Treatments

The study is comprised of three crop rotations and three tillage intensities. The rotations are continuous cropping, crop-crop fallow and crop-fallow. The tillage intensities are conventional tillage, minimum tillage and no tillage (direct seeding). The crop during the five years is spring wheat.

Each individual treatment plot is 30m X 18m in size. There are a total of 12 treatment plots. That is three continuously cropped plots with each tillage intensity present, the three crop-crop fallow plots with the three tillage intensities represented and six plots for the crop-fallow rotation. The six plots for the later rotation is so that in each year both a fallow and a cropped treatment for each tillage type is present.

Field Operations

All field operations are done using field size equipment according to accepted practices. All herbicide applications and rates are done according to labelled instructions.

Continuously Cropped Operations: For the three continuously cropped treatments the seedbed preparations are as follows:

(i) No-tillage: The plot is sprayed in the fall (postharvest by mid-October) with 2,4-D (0.5 L/ac, 500g/L concentration) if winter annual weed growth is present. In the spring the next year the plot is sprayed with Round-up at 0.7 L/ac in mid-May one week before direct seeding using a conservation tillage seed drill.

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(ii) Minimum-tillage: This plot is sprayed in the fall in the same manner as the no-till plot. In the spring prior to seeding the plot is cultivated and harrowed once before seeding.

(iii) Conventional-tillage: There is no fall applied herbicide in this treatment. The plot is cultivated and harrowed three times before seeding.

Each of the continuously cropped plots receives 60kg/ha (60lb/ac) of nitrogen pre-plant banded before seeding or during the seeding operation depending on the seed drill used.

Crop-Crop-Fallow Operations: In the year of recropping the seedbed preparation and other work is identical to that noted above for the continuously cropped treatments. In the year of the fallow the field work for the three tillage types is as follows:

(i) No-tillage (Chemical or Conservation Fallow): After harvest of the previous crop the plot is sprayed with 2,4-D as noted for the no-till continuous cropped plot. Plant growth during the fallow year is controlled using three to four applications of Rustler (1.5L/ac). The timings and need of application depending on weed growth.

(ii) Minimum Tillage: The plot is sprayed with 2,4-D in the fall as noted above. This spray operation usually allows the delay of the first cultivation during the fallow year until the end of May. The plot is cultivated two to three more times during the fallow year as required to control plant growth.

(iii) Conventional Tillage: The plot is usually cultivated five to six times during the fallow year depending on weed growth. The first cultivation is done by mid-May.

In the year following the year of fallow both of the tilled plots are cultivated and harrowed once before seeding. The no-till plot is sprayed with Roundup (0.7L/ac) one week before seeding.

Crop-Fallow Operations: The field work for the year of fallowing and the year following the fallow year are the same as those outlined for the Crop-Crop-Fallow rotation above.

The in-crop spraying of cropped plots in each year is identical for all the rotations and tillage types. It is usually an application of Hoe-Grass II (1.4L/ac). All of the seeded plots receive 60kg/ha (60lb/ac) of 11-55-0 fertilizer in the seedrow.

Ten yield samples are taken off each cropped plot each fall. The samples are taken randomly from the individual plot. After threshing of the samples the yield results are analyzed using an unpaired T-test.

RESULTS

As the study involves a rotational study not all of the treatment plots can provide yield results each year. This is because the site

was located in a field that had been cropped to spring wheat in 1985. The available yield results for 1986 are the continuously cropped treatments only. In the subsequent years yields are available from the other treatments. For the Crop-Crop-Fallow rotation yield results are available for only two out of three years of the rotation as only one phase of the rotation is present in any given year.

The yield results for the years 1986,87, and 88 are summarized below in the following tables.

Table 1. Crop Yields 1986, by Rotation and Tillage Type

Rotation	Tillage Type	Crop Yield kg/ha	(bus/ac)	
Continuously Cropped	Tillage	3200	(48)	a*
Continuously Cropped	Minimum Tillage	3200	(48)	a
Continuously Cropped	No-tillage	3300	(50)	a

* yields followed by letter do not differ significantly as determined by unpaired T-test (P_0.05).

Table 2. Crop Yields 1987, by Rotation and Tillage Type

Rotation	Tillage Type	Crop Yield kg/ha	(bus/ac)	
Continuously Cropped	Tillage	1600	(23)	a
Continuously Cropped	Minimum Tillage	1500	(22)	a
Continuously Cropped	No-tillage	1700	(25)	a
Crop-Fallow	Tillage	2600	(37)	b
Crop-Fallow	Minimum Tillage	2200	(32)	b
Crop-Fallow	No-Tillage	2400	(34)	b

* Yields followed by the same letter do not differ significantly as determined by unpaired T-test (P_0.05).

Generally speaking there has not been a large difference between tillage types that are in the same rotation. This was true for the 1986 and 87 results. In 1988 however, due to the severe drought in the M.D. of Provost the minimum tillage and no-tillage treatments out yielded the conventional tillage treatment for the continuous cropped rotation and the rotations including fallow. The yield advantage shown in the minimum and no-tillage is attributed to conserved moisture because of less seedbed tillage.

The results of 1987 and 88 show that the yields of the continuously

Table 3. Crop Yields 1988, by Rotations and Tillage Type

Rotation	Tillage Type	Crop Yield kg/ha (bus/ac)
Continuously Cropped	Tillage	1000 (15) a
Continuously Cropped	Minimum Tillage	1500 (22) b
Continuously Cropped	No-tillage	1800 (27) b,c
Crop-Fallow	Tillage	1300 (18) a
Crop-Fallow	Minimum Tillage	na - equipment problem
Crop-Fallow	No-Tillage	2100 (31) c
Crop-Crop-Fallow	Tillage	1000 (15) a
Crop-Crop-Fallow	Minimum Tillage	1500 (22) b
Crop-Crop-Fallow	No-Tillage	1800 (27) b,c

na-not available
* yields followed by the same letter do not differ significantly as determined by unpaired T-test (P_0.05).

cropped treatments are less than those following a year of summer fallow.

FURTHER COMMENTS

The conservation tillage demonstration located near Provost (4km east of Provost on Highway 13) has been used effectively to increase awareness of the potential use of conservation tillage practices. The project has been used for a number of field tours and the yield results have been used at numerous conservation tillage meetings the last couple of years. A detailed summary report will be prepared in late 1990 at the conclusion of the project. This report will include a general economic assessment in addition to the yield result comparisons.

WINTER WHEAT PRODUCTION ON STANDING STUBBLE

R. C. McKenzie[1]

INTRODUCTION

In order to conserve soil, farmers in Alberta are encouraged to grow winter wheat on stubble rather than on fallow. Summerfallow leaves an exposed soil surface which is susceptible to wind and water erosion, causes excess moisture to accumulate which can contribute to the formation of saline seeps.

Most of the winter wheat in Alberta is grown on fallow in southern Alberta. Farmers in central Alberta are reluctant to grow winter wheat because of the risk of the severe winters killing the crop. The Crop Development Centre at the University of Saskatchewan has shown that if winter wheat is seeded directly into standing stubble, enough snow is trapped to prevent the soil temperature from dropping sufficiently to cause winter kill. Winter wheat seeded into stubble is now grown throughout Saskatchewan in areas which have similar climate to east central Alberta. This technique of seeding directly into untilled stubble coupled with the development of minimum till drills and a new high quality winter hardy cultivar, Norstar, means it is now possible to grow winter wheat in central Alberta.

Winter wheat grows slower and at lower temperatures than spring wheat and therefore is able to make more efficient use of moisture than spring wheat. Those areas which have good spring moisture should have more success growing winter rather than spring wheat on stubble.

There are advantages to growing winter wheat rather than spring wheat. Winter wheat makes more efficient use of spring runoff than does spring wheat. This means winter wheat on stubble will likely be more successful than will spring wheat on stubble. The use of a mix of winter and spring crops provides an increased spread of time for seeding and harvesting to make better use of equipment and labour.

METHOD

In 1985, Alberta Agriculture Regions I and II provided funds for On-Farm Demonstration of winter wheat on stubble in East Central Alberta. Funds were administered by the farmers and the plots were seeded and harvested by Alberta Agriculture staff at Brooks. Seed drills were provided by Vicon Ltd. of Nobleford, Alberta.

In 1985-86, winter wheat demonstrations were grown at Iddesleigh, Oyen, Hanna, Gadsby, and Kirriemuir. These demonstrations consisted of a 1.6-ha plot of winter wheat seeded with a hoe drill and a similar area with a disc drill. In 1986-87 and 1987-88 winter wheat was grown only at Kirriemuir and Iddesleigh. The demonstration sites in 1986-87

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and 1987-88 also included a small experimental area of 0.25 ha which contained replicated treatments of seeding rates, seeding methods, N fertilizer rates and times of application, and at Iddesleigh it also contained two seeding dates treatments.

Each plot was 2.4 m x 7.5 m and consisted of one pass of a drill. The 1986-87 crop was harvested with a plot combine and the 1987-88 crop was harvested by clipping one meter square samples. This report contains the results from the 1987-88 experiments and is a review of the results of 1985-86 and the 1986-87 experiments. Detailed reports by McKenzie 1987 and McKenzie and Clark 1988 on the 1985-86 and 1986-87 experiments are cited in the references to this report.

RESULTS AND DISCUSSION

Seeding Methods

The hoe and a disc drill were used at all sites. In two cases adjacent fields were seeded by the farmer with an air seeder. The disc drill plugged less frequently than the hoe drill.

In most cases, the yields from plots seeded with either the hoe or disc drill were smaller. At the Oyen site in 1985-86 liquid fertilizer was injected (at 6000 psi) into the soil behind the disc drill. This process uncovered and damaged some seed, which may have been the reason that the disc drill treatments at this site yielded slightly less than the hoe drill treatments. At Iddesleigh in 1986-87 yields from treatments seeded with the hoe drill were 0.61 and 0.91 t/ha more than equivalent treatments seeded with the disc drill (Fig. 1). At the Kirriemuir site in 1987-88 there was little difference in yield between treatments seeded with the hoe drill and disc drill (Fig. 2).

Seeding Rates

Three seeding rates were used in 1986-87 and 1987-88 (Table 1 and Table 2). At both sites in 1987-88 yield was low and not influenced by seeding rate. At Kirriemuir in 1986-87 seeding rates of 50, 78 and 112 kg/ha did not significantly influence the yield (Fig. 2). At Iddesleigh in 1986-87 seed yield was higher with increased seeding rate on both hoe and disc drill treatments. Seeding rates of 45, 65, and 93 kg/ha with the disc drill produced crops which yielded 0.82, 0,95, and 1.58 t/ha, respectively (Fig. 3).

Cultivated Stubble vs Standing Stubble

Treatments in which stubble was cultivated prior to seeding were included in the 1986-87 and 1987-88 experiments. The average yield at Iddesleigh for standing was 1.12 t/ha and for cultivated stubble was 0.80 t/ha in 1986-87. The equivalent values for Kirriemuir in the same year were 0.71 and 0.50 t/ha. The 1987-88 yields on cultivated stubble were again lower than those on standing stubble at both sites (Fig. 4 and 5).

Table 1. Yields, rates and time of seeding and fertilizer applications for 1987-88

	Seeding			Fertilizer		
Site Cultivation	Method	Date	Rate kg/ha	Rate kg/ha*	Date	Yield t/ha#
Iddesleigh						
standing stubble	disc	Aug 28	46	33	April	0.064
standing stubble	disc	Aug 28	67	0		0.053
standing stubble	disc	Aug 28	67	33	April	0.038
standing stubble	disc	Aug 28	67	66	April	0.025
standing stubble	disc	Aug 28	100	33	April	0.056
standing stubble	disc	Aug 28	67	33	Sept	0.025
standing stubble	disc	Sept 15	45	33	April	0.178
standing stubble	disc	Sept 15	67	33	April	0.215
standing stubble	disc	Sept 15	100	33	April	0.216
standing stubble	hoe	Aug 28	45	33	April	0.044
standing stubble	hoe	Aug 28	67	33	April	0.004
standing stubble	hoe	Aug 28	100	33	April	0.065
cultivate	disc	Aug 28	45	33	April	0.030
cultivate	disc	Aug 28	67	33	April	0.042
cultivate	disc	Aug 28	100	33	April	0.048
Kirriemuir						
standing stubble	disc	Sept 21	51	33	May	0.095
standing stubble	disc	Sept 21	71	0		0.169
standing stubble	disc	Sept 21	71	33	May	0.116
standing stubble	disc	Sept 21	71	67	May	0.069
standing stubble	disc	Sept 21	106	33	May	0.079
standing stubble	disc	Sept 21	71	33	Sept	0.097
standing stubble	hoe	Sept 21	71	33	May	0.181
standing stubble	hoe	Sept 21	106	33	May	0.148
cultivate	disc	Sept 21	51	33	May	0.030
cultivate	disc	Sept 21	71	33	May	0.026
cultivate	disc	Sept 21	106	33	May	0.090

Early Seeding vs Late Seeding

Date of seeding treatments were included at Iddesleigh in 1986-87 and 1987-88. In 1986-87 the average yield of what seeded August 27 was 1.32 t/ha and October 7 0.83 t/ha. In 1987-88 the average yield of wheat seeded August 28 and September 15 was 0.053 and 0.203 t/ha, respectively. The higher yield of the late seeded treatments in 1988 was due to a dry winter and drought in April and May which caused more severe damage to the early seeded than the late seeded winter wheat.

Rates and Times of Nitrogen Fertilizer

These treatments were applied at Iddesleigh and Kirriemuir in 1986-87 and 1987-88 (Fig. 6 and Fig. 7). Each site in both seasons had an adequate supply of soil nitrogen for the crop that was produced.

Table 2. Yields, rates and time of seeding and fertilizer applications for 1986-87

Site Treatment	Seeding Method	Seeding Date	Seeding Rate kg/ha	Fertilizer Date	Fertilizer Rate kg/ha*	Grain Yield t/ha#
IDDESLEIGH						
Seeding Rate						
Standing	disc	Aug 27	93	April	25	1.58
Standing	disc	Aug 27	65	April	25	0.95
Standing	disc	Aug 27	45	April	25	0.82
Cultivate	disc	Aug 27	93	April	25	0.99
Cultivate	disc	Aug 27	65	April	25	0.72
Cultivate	disc	Aug 27	45	April	25	0.70
N Fertilizer						
Standing	disc	Aug 27	65	April	50	0.99
Standing	disc	Aug 27	65	April	25	0.95
Standing	disc	Aug 27	65	April	0	0.88
Standing	disc	Aug 27	65	Oct	50	1.18
Dates - High Seeding Rates						
Standing	disc	Aug 27	93	April	25	1.58
Cultivate	disc	Aug 27	93	April	25	0.99
Standing	disc	Oct 07	93	April	25	0.95
Dates - Medium Seeding Rates						
Standing	disc	Oct 07	65	April	25	1.07
Standing	disc	Aug 27	65	April	25	0.95
Cultivate	disc	Aug 27	65	April	25	0.72
Method at Medium and Low Seeding Rates						
Standing	hoe	Aug 27	65	April	25	1.86
Standing	disc	Aug 27	65	April	25	0.95
Standing	hoe	Aug 27	45	April	25	1.46
Standing	disc	Aug 27	45	April	25	0.82
KIRRIEMUIR						
Seeding Rate						
Standing	hoe	Sep 11	112	April	75	0.76
Standing	hoe	Sep 11	78	April	75	0.68
Standing	hoe	Sep 11	50	April	75	0.69
Standing	disc	Sep 11	78	April	75	0.73
Cultivate	hoe	Sep 11	112	April	75	0.50
Cultivate	hoe	Sep 11	78	April	75	0.44
Cultivate	hoe	Sep 11	50	April	75	0.58
Cultivate	disc	Sep 11	78	April	75	0.49
N Fertilizer						
Standing	hoe	Sep 11	78	April	110	0.59
Standing	hoe	Sep 11	78	April	75	0.68
Standing	hoe	Sep 11	78	April	35	0.72
Standing	hoe	Sep 11	78	Oct	75	0.72
Seeding Method at Two Seeding Rates						
Standing	disc	Sep 11	50	April	75	0.79
Standing	hoe	Sep 11	50	April	75	0.69
Standing	disc	Sep 11	78	April	75	0.73
Standing	hoe	Sep 11	78	April	75	0.68

*1 kg/ha = lb/ac

#1 t/ha = 14.8 bu/ac

The fall fertilized treatment at Iddesleigh in 1986-87 yielded 0.19 t/ha more than the similar spring fertilized treatment at each site in each year. There was no advantage to increasing rates of nitrogen fertilizer.

Actual and Average Precipitation at Winter Wheat Plot Sites

Actual and average precipitation are shown in Fig. 8. The most critical period for moisture supply for winter wheat is April to June. Only the Gadsby site (8c) in 1985-86 had above average precipitation during this period contributing to yields of 3.7 and 3.5 t/ha for the hoe and disc drill treatments respectively. Oyen (8a) in 1985-86 had a dry winter and early spring with above average precipitation in May. A grasshopper infestation reduced the potential yield at this site (Table 3). In 1985-86 Hanna 8b, Iddesleigh 8d, and Kirriemuir 8e, had below normal precipitation in the winter and spring.

Table 3. Demonstration plot winter wheat yields in t/ha* for 5 sites in 1985-86

Seeding Method	Gadsby	Oyen	Hanna	Iddesleigh	Kirriemuir
Hoe drill	3.7	1.24	1.4	0.50	2.0
Disc drill	3.5	1.13	1.3	0.52	2.1

*1 t/ha = 14.8 bu/ac

In 1986-87 both Iddesleigh (8c) and Kirriemuir (8e) had below normal precipitation in May and June. July rain at Kirriemuir was too late to benefit the winter wheat. In 1986-87 a dry fall and winter and little rain in April and May resulted in a crop failure at both sites. Average precipitation occurred during June, July, and August but again this rain was too late to benefit the winter wheat crop (8h, 8i) at both sites.

Winter wheat will respond differently to seasonal rainfall distribution than spring wheat. At Swift Current, Campbell and Zentner (personal communication) found that the critical months for rainfall on spring wheat on stubble is prior to emergence and in June. The critical time for spring wheat on fallow is July. It appears that rainfall in September and May to June is essential to winter wheat. At Gadsby, near Stettler in central Alberta, average precipitation amounts to 72 mm for May and June and 142 mm for July and August. This rainfall distribution would favor spring wheat. For the other site, average rainfall in millimetres for May and June vs July and August is 104 and 114, for Hanna 94 and 119, for Kirriemuir 123 and 78, for Oyen and 109 and 82 Iddesleigh. It is preferable to produce winter wheat rather than spring wheat at Oyen and Iddesleigh. These sites have the lowest average rainfall and the highest evapotranspiration of the five sites so they would be risky locations for wheat on stubble. Winter wheat should also be tested in these areas as a crop on chemical fallow.

Winter Survival

The winter survival of winter wheat has been a concern in central Alberta. In this project on nine site years over a period of three years winter kill was not a problem. In the spring of 1988 the stand was very thin due to winter killing on a hill at one corner of the Iddesleigh site. This was where trucks had turned and tractors were loaded and the stubble was flattened. This hill then did not hold snow which serves to insulate the soil from severe low temperatures and prevent winter killing.

In the fall of 1987 emergence was poor at both Iddesleigh and Kirriemuir due to dry soil conditions, resulting in thin stands in 1988.

The variety Norstar is sufficiently winter hardy for use under stubble conditions in central Alberta.

Future of Winter Wheat

Farmers in central Alberta are still unconvinced of the merits of growing winter wheat. Initial prices are low on winter wheat. This discourages production even though final payments have reduced the spread between winter and spring wheats. Only one of the six farmers who had demo plots, W. Olson, at Iddesleigh has continued to grow winter wheat. He now grows it on summerfallow to stabilize the soil and prevent drifting. It remains to be determined if winter wheat on fallow is winter hardy in a severe winter like 1988-89.

CONCLUSIONS

- Generally the treatments seeded with the hoe and disc drill produced similar yields of wheat. In one year at two sites treatments seeded with the hoe drill yielded more than the disc drill.

- The disc drill cleared trash better than the hoe drill.

- High seeding rates yielded more than low seeding rates in 1986-87. This was a year with dry conditions and low emergence in the fall.

- No response to nitrogen occurred in 1986-87 and 1987-88 experiments. The sites had above average soil nitrogen and crop yields were low.

- Winter wheat seeded in late September or early October usually yielded less than winter wheat seeded in late August.

- Winter wheat seeded into cultivated stubble yielded less than wheat seeded into standing stubble.

- Only Oyen and Iddesleigh have average rainfall in May and June which exceed the average rainfall of July and August. These areas should normally have more success with winter wheat than spring wheat. In the 3 years this project was conducted, most of the sites had low fall and early spring rainfall. This meant winter wheat often yielded less than spring wheat.

- Norstar winter wheat proved to be winter hardy at all sites.

- More research should be done on winter wheat in those areas which receive good precipitation in May and June. Winter wheat should also be compared to spring wheat on chemical fallow in areas where precipitation is low and stubble cropping is risky.

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R. C. McKenzie and N. F. Clark. 1988. Winter Wheat Production on Standing Stubble, Soil and Water Program 1987, ASCHRC Pamphlet 88-10 April 1988 Available from Alberta Special Crops and Horticultural Research Center, Brooks, Alberta pp. 33-39.

Fig. 1 Effects of Seeding Methods at Three Seeding Rates on Winter Wheat at Iddesleigh 1986–87

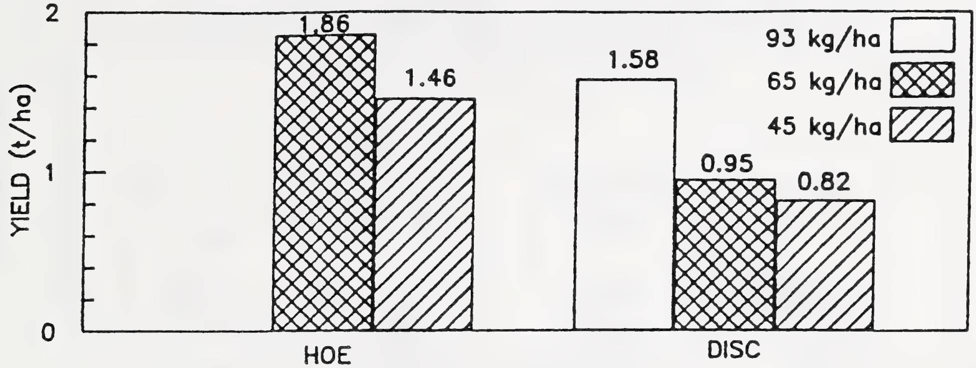


Fig. 2 Effect of Seeding Methods and Tillage at Three Seeding Rates on Winter Wheat at Kirriemuir 1986–87

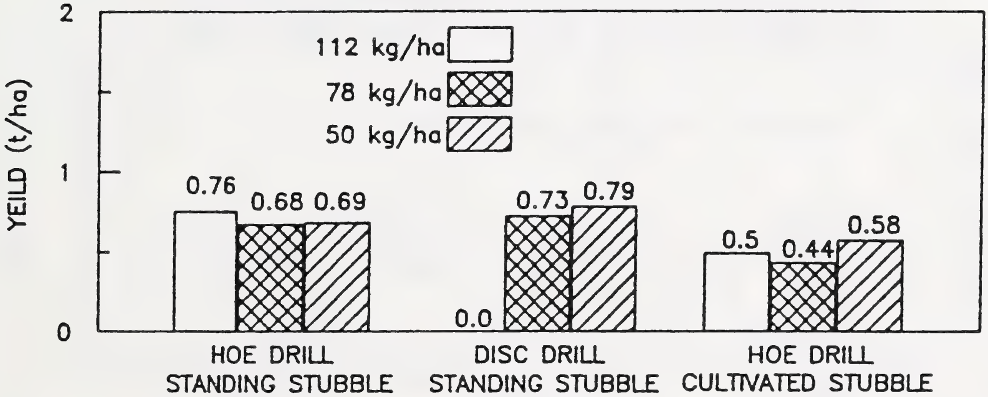


Fig. 3 Effect of Seeding Rates, and Dates With a Disc Drill on Winter Wheat at Iddesleigh 1986–87

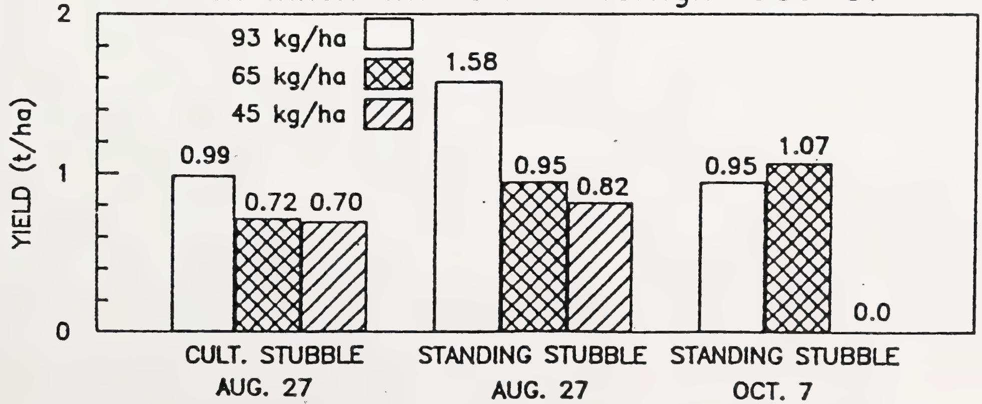


Fig. 4 Effect of Seeding Method, Cultivation and Date on Winter Wheat at Iddesleigh 1987–88

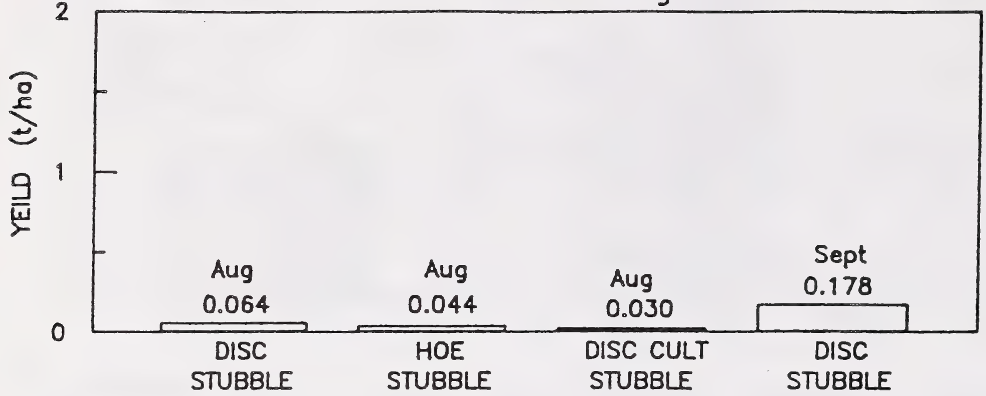


Fig. 5 Effect of Seeding Method and Cultivation on Winter Wheat at Kirriemuir 1987–88

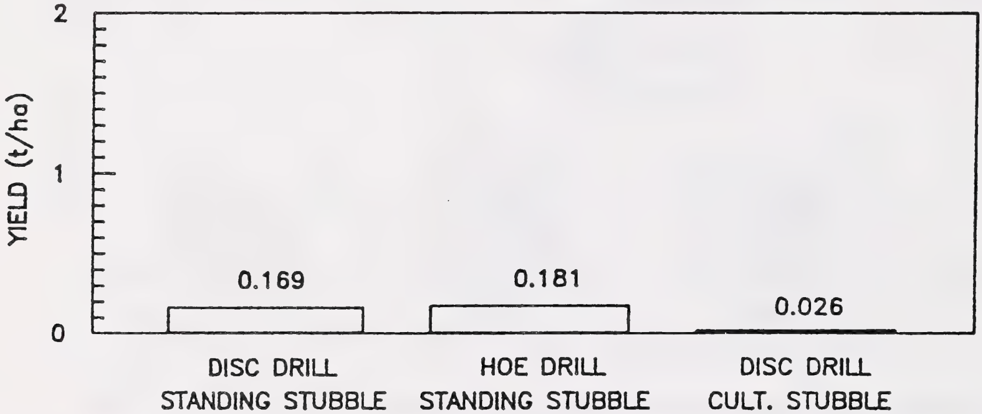


Fig. 6 Effect of Rate and Time of Application of Nitrogen on Winter Wheat at Iddesleigh 1986–87

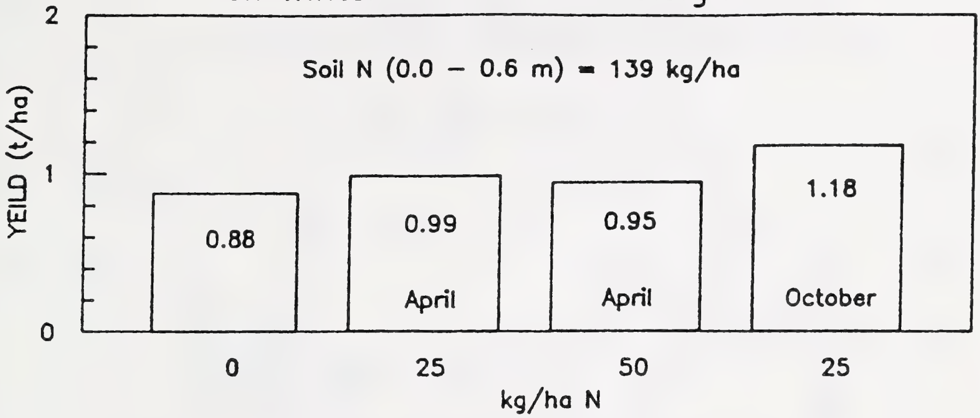


Fig. 7 Effect of Rate and Time of Application of Nitrogen on Winter Wheat at Kirriemuir 1986–87

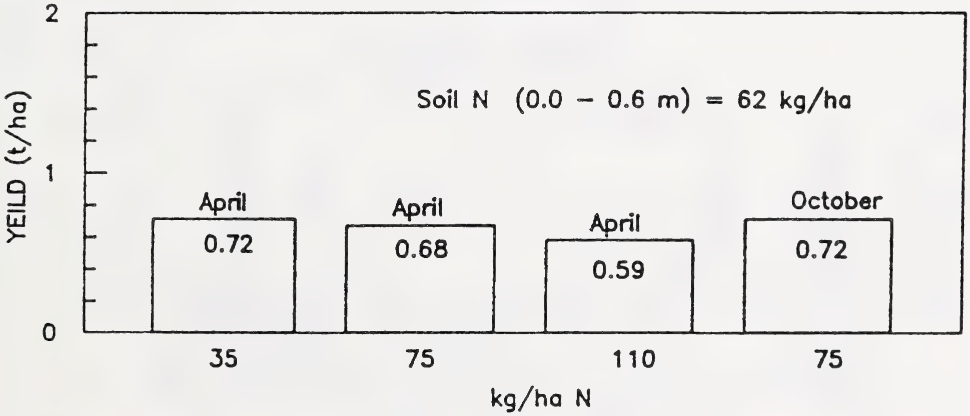
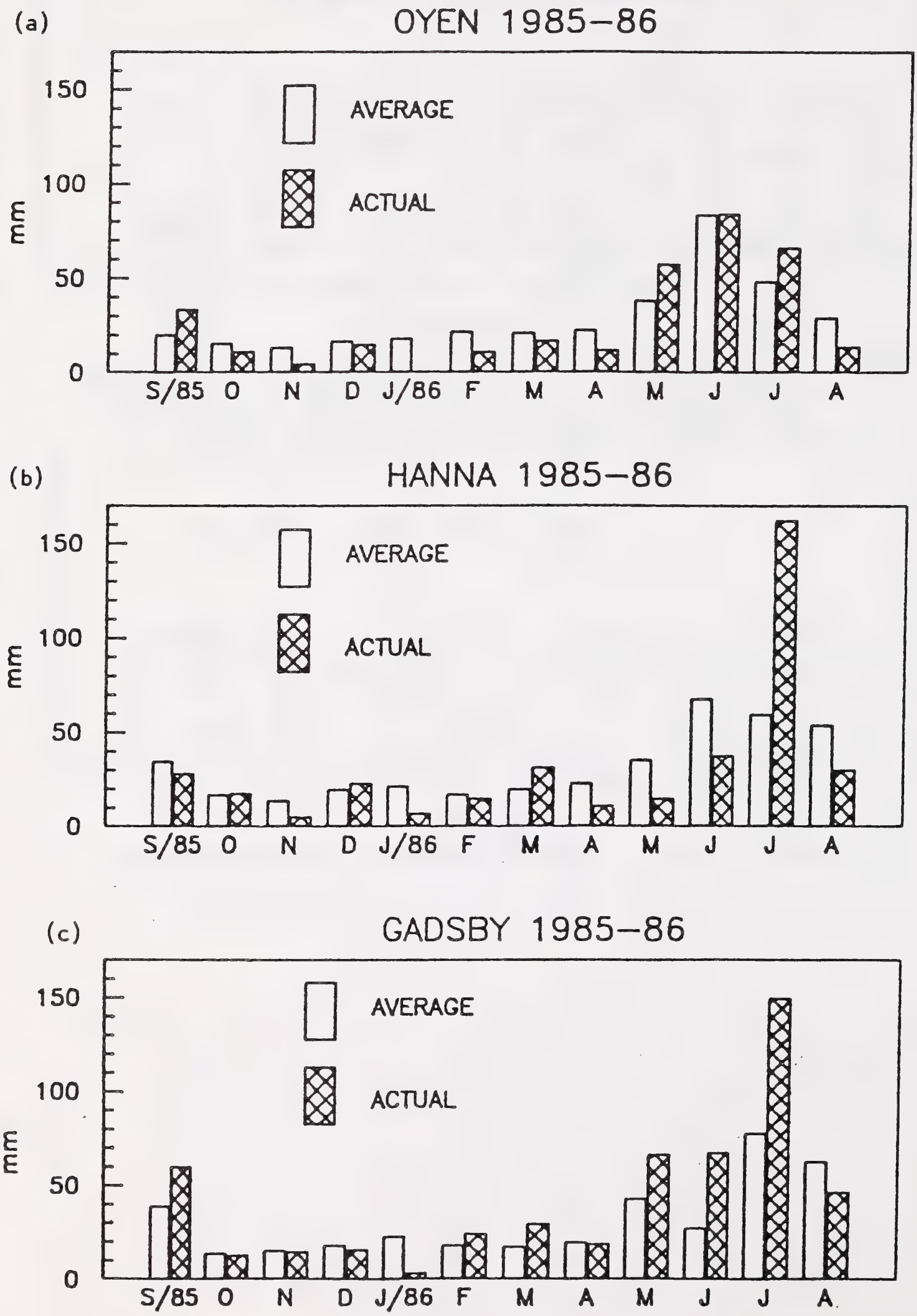
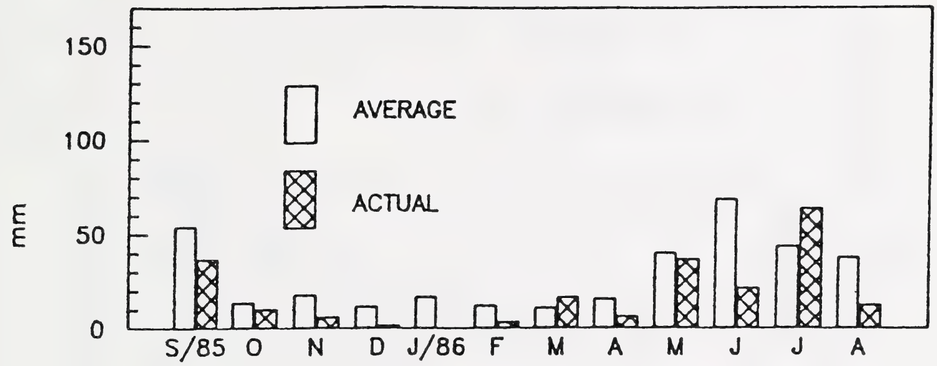


Fig. 8 ACTUAL AND AVERAGE PRECIPITATION

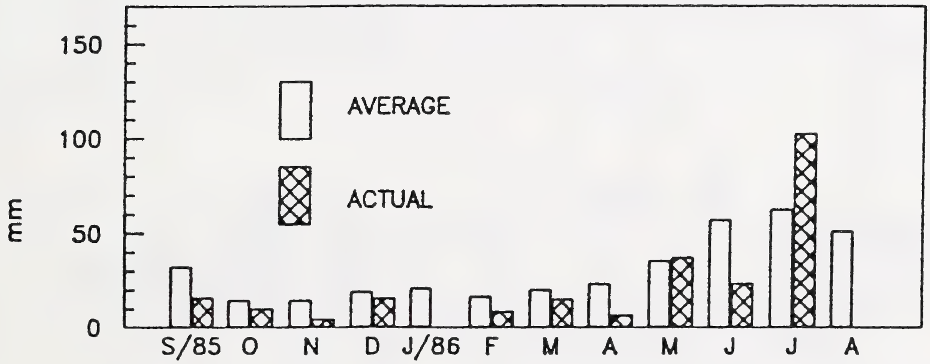
AT WINTER WHEAT PLOT SITES



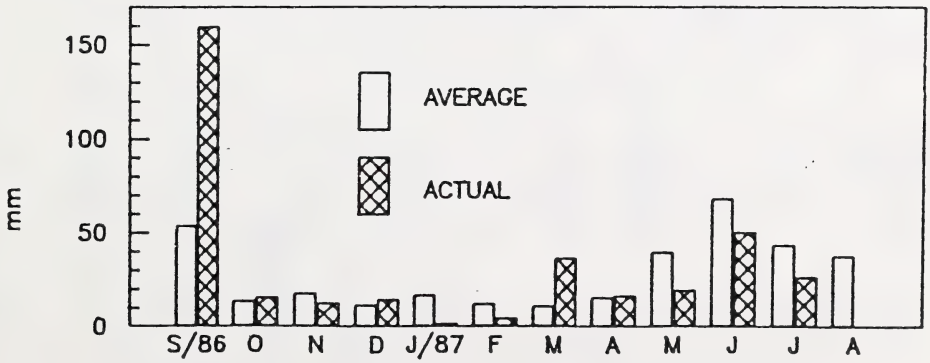
(d) IDDESLEIGH 1985–86



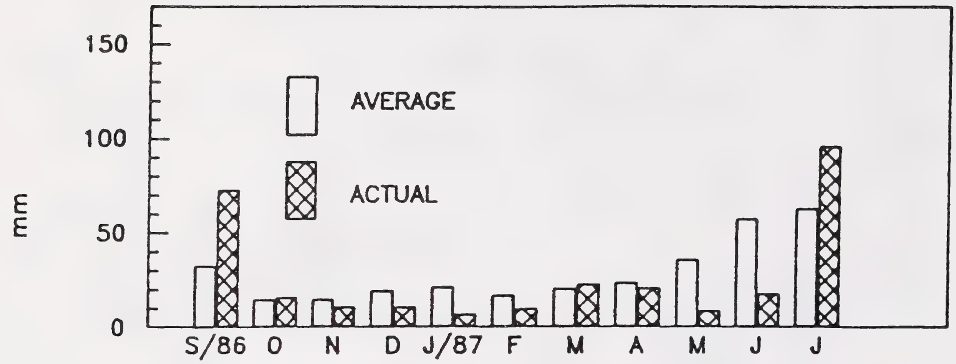
(e) KIRRIEMUIR 1985–86



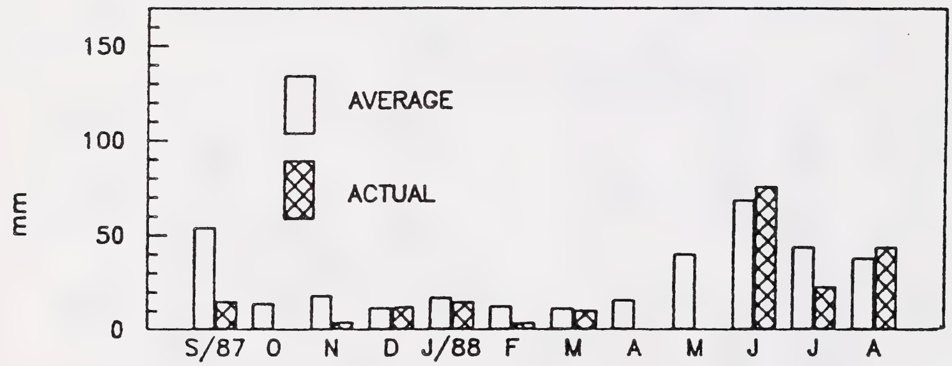
(f) IDDESLEIGH 1986–87



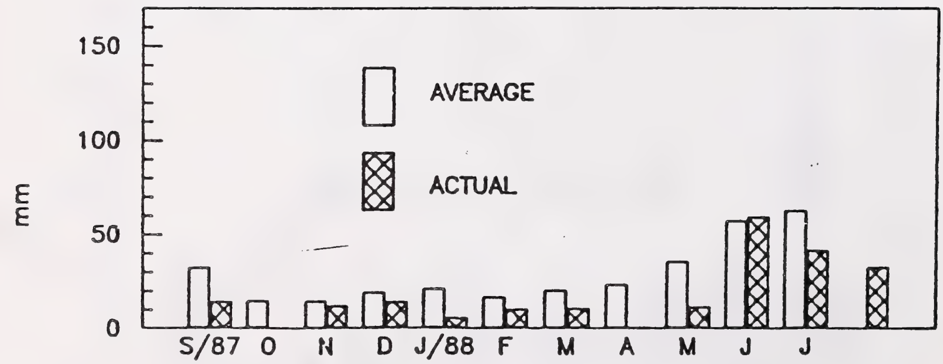
(g) KIRRIEMUIR 1986–87



(h) IDDESLEIGH 1987–88



(i) KIRRIEMUIR 1987–88



SOIL TILTH AS AFFECTED BY ORGANIC MATTER AND SODICITY INTERACTIONS

Bill Read[1]

INTRODUCTION

High sodium levels in soils which are low in organic content frequently result in the establishment of a poor seedbed. It is possible that the low organic content is as much a limiting factor for soil tilth as are high sodium levels. If this is the case, good soil tilth might be attained when an optimal balance between sodium and organic content exists. Both water infiltration rate and seed germination percentage are manifestations of soil tilth. These processes are adversely affected as soil sodium levels increase and as organic matter content decreases, promoting soil dispersion and crusting. The relative and interactive impact of sodium absorption ratios (SAR's) and organic content has not been assessed. This information is essential for predicting water movement into sodic soils (for cropping and reclamation applications), and also for water quality assessment. The intent of this study was to determine how interactions between organic content and sodicity impact soil tilth.

METHODS

For determination of hydraulic conductivity, aggregate stability and the influence on germination rate, surface soil samples (0 - 25 cm depth) were collected from the four Alberta soil zones (gray, black, brown and dark brown). Three sites within each zone were sampled in order to obtain a range in soil textures; (fine, medium and course).

Field texturing and laboratory particle-size analysis was conducted on each sample collected to determine soil texture. Each sample was initially sieved through a 2 mm screen. Individual samples were mixed in a cement mixer, so that homogeneity in organic matter and soil aggregate distribution throughout each soil could be achieved.

Chemical profiles were determined for each soil. This information was used to derive Na_2SO_4 amounts required to amend each soil to SAR (sodium absorption ratio) levels of approximately 4, 8, 14 and 32. Organic carbon content was also determined.

Control samples for all analyses consisted of non-amended soils. SAR determination was based on 100g samples. To amend smaller and larger sized testing samples, the Na_2SO_4 required was adjusted appropriately. For example, in order to amend samples of 600 gms, Na_2SO_4 amounts were increased by six times.

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Germination

For determining percent germination of alfalfa in soils with increasing SAR levels, six hundred gram samples of each soil collected were amended to SAR's of 4, 8, 14 and 32.

Field moisture capacity was determined by saturating each sample and allowing them to drain completely. Samples of the saturated soils were oven dried and moisture percentages were calculated. These percentages represented 100% field capacity. To eliminate the possibility of drainage of water and hence movement of salts, a level of 80% field capacity was determined for each soil. This involved adding a water equivalent weight of ice to each sample. Five hundred c.c. pots were filled with 600 gms of sample, which provided an approximate soil density of 1.2 g/cm^3. Each sample was replicated four times.

Beaver alfalfa was seeded to a depth of 1 cm at a rate of five seeds per pot (10 cm dia). This seeding rate was based on recommended field seeding rates of 1.76 kg/ha.

To maintain a moist environment for germination, each pot was covered with a clear poly tent to prevent excess evaporation from the soil surface. The temperature was maintained at 10°C with a daylight period of 16 hrs.

Hydraulic Conductivity

The constant head method for determining hydraulic conductivity was used. This method is frequently used for sandy, loam and occasionally clay loam textured soils with rapid hydraulic conductivities (ie: greater than 0.5 cm/hr). The constant head method was the most appropriate for determining hydraulic conductivities within the textural range of soils collected for this study.

Copper cylinders of a volume 694.9 cm^3 were fitted with cheesecloth bottoms and lined with filter paper to create an effective cylinder allowing water flow through the soil and collection of the percolate in a container below.

Each cylinder was filled with 400 g of soil. Two replicates of each soil were prepared, including non-amended controls in addition to SAR's of 4, 8, 14 and 32 for the twelve soils collected. A total of 120 samples were run.

Each soil cylinder was compacted by lifting and dropping it a distance of 25 mm for 20 repetitions. The cylinders were placed in a tray filled with about 5 cm of tap water for six hours. The water level in the tray was gradually raised until it reached a point just below the top of the samples. Samples were saturated from the bottom up to allow air to escape up through the top of the samples.

The samples were left to saturate for at least 24 hours. Fine textured soils were saturated for 48 hours. Once saturation was achieved, filter paper was placed on top of each sample and tap water was slowly added into the upper reservoir until it was 3/4 full.

Samples were then transferred to a rack and a syphon was started to maintain a constant head of water to each sample. The volume of water which passed through each of the samples during one hour increments of time was recorded. Samples were run until a steady or constant measurement was obtained. At least four readings were taken per session.

Aggregate Stability

The direct immersion method of wet sieving is recommended for determining aggregate stability as related to the formation of soil crusts. Since crusting is one aspect of soil tilth, direct immersion wet sieving was used.

Fifty grams of air dried soil was added to a sieve nest. The nest consisted of a series of four sieves: 4.76 mm, 2.00 mm, 1.00 mm and 0.21 mm. The sieves were stacked on top of each other in increasing order of size from fine to course.

The nest was raised and lowered a distance of approximately 4 cm in a mechanical wet sieving device at a rate of 33 oscillations per minute, for 30 minutes. The sieve nest was removed from the water and allowed to drain. The sieves were separated, placed on metal plates and completely oven dried at 110°C. The dried aggregates were brushed from the screens and weighed. Mean weight diameters were calculated. Each sample was run in duplicate.

RESULTS

Data analysis for this project was not complete by the submission deadline, therefore, the results will be reported at a later date.

TESTING AND CALIBRATION OF THE EM31 ELECTROMAGNETIC SOIL CONDUCTIVITY METER

Bill Read[1]

INTRODUCTION

In the past, the determination of soil salinity in a field setting has been a labour-intensive activity. The recent refinement in the application of electromagnetic soil conductivity meters, particularly the EM31 and the EM38, has made the process much easier.

The EM31 is a device which has the potential capability of quickly measuring salinity to a depth of six metres, and facilitating dryland investigations by dramatically increasing the data gathered. There is also potential for mapping salinity at depth with low labour requirements. The EM31 could further be used for rapid diagnosis of saline-waterlogged conditions which would speed up dryland salinity investigations and reclamation monitoring.

A project was designed which would identify the conditions which affect the EM31 readings and develop a set of correction factors as had been previously done for the EM38. This project was also designed to determine whether the EM31 could be used to measure the depth to a water table.

METHODS

The EM31 is an electromagnetic conductivity meter designed to rapidly measure field soil conductivity without requiring soil contact. The unit is comprised of a self-contained dipole transmitter located at one end and a self-contained dipole receiver at the other end separated by an intercoil spacing of 3.7 metres. The transmitter, when energized, produces an electromagnetic field that induces current flow in the soil. The magnitude of the current flow is proportional to the bulk electrical conductivity of the soil through which the current passes. This current produces a secondary electromagnetic field which is sensed by the receiver and converted to an output voltage. The output voltage is linearly related to the bulk soil electrical conductivity. The EM31 was initially designed for shallow geophysical exploration and is generally responsive to conditions within the top 6 m of the soil. It is not as sensitive in the top 2 m as the EM38, which has a shorter intercoil spacing and was specifically designed for soil salinity investigation.

Data were gathered at soil salinity investigation sites which contained a water table well and had soil logs available from earlier test drilling. The test sites were located throughout southern Alberta primarily in the Milk River, Foremost, Acadia Valley, Hanna and Arrowwood areas. These locations provided a variety of soil types and salinity levels from which to collect data. A total of 33 sites were initially visited, but this number gradually declined to 29 as some sites were distrupted by farming activities.

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Data collection at each site consisted of reading soil salinity with the EM31 meter and the EM38 meter; measurement of the depth, quality and temperature of the groundwater; determination of the soil moisture by gravimetric sampling, in 25 cm increments to a depth of one metre; and measurement of the soil temperature at a depth of one metre.

Data collection took place on a monthly basis from July through October 1988, and from May through September 1989. This allowed documentation of the effect of a range of soil temperatures and soil moisture levels on soil salinity readings. Gravimetric sampling was suspended in the winter months because of frozen soils, and because most sites were not accessible due to snow cover. Data were collected at soil temperatures that ranged from 0 to 22 °C.

RESULTS

As data collection did not conclude until September, 1989, the development of calibration curves were not complete by the submission deadline. Therefore, results from this project will be reported at a later date.

RAPID MAPPING OF SALINITY USING AN EM38 METER

R. C. McKenzie and N. F. Clark[1]

INTRODUCTION

This report outlines the equipment required to map salinity with an EM38 meter and a data logger. The EM38 is an electromagnetic induction meter which reads soil salinity directly from the ground surface. The meter can be connected to a data logger and readings can be collected and stored in a form to make a contour map of soil salinity. Equations have been developed which allow conversion of EM38 readings to saturated paste extract ECe equivalents for preparation of maps.

MATERIALS	SOURCE
1. EM38	Geonics 1745 Meyerside Drive Mississauga, Ontario, Canada L5T 1C5
2a) Analog to Digital Converter	Paulson Electronics 10548 - 80 Avenue EDMONTON, Alberta, Canada
b) Data Logger (Tandy 102)	Radio Shack

There are several data loggers in the market. The reason that we chose the Tandy 102 is that we were able to get an analog-to-digital converter which was developed to accommodate the EM38-Tandy connection. To use another type of data logger would require developing a converter or making the necessary adjustments to an existing converter.

3. Magnetic Proximity Switch	Radio Shack

These switches are available at a number of places and in a variety of models. The one that we use is a Normally Open switch similar to those used to trigger door alarms. A hand operated push button switch should also be constructed to provide data logging for those conditions where it is not feasible to tow the meter behind a vehicle.

4. Connector Cables	Various Sources

a) EM38 to Converter

The connectors on the EM38 have varied considerably over the years so it is important to get the appropriate one for your cables.

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b) Data Logger to Proximity Switch

This cable connects to the printer port on the data logger and the proximity switch. The switch has to be mounted on a fixed support near a wheel so that it will be tripped by the magnet as it passes the proximity switch on the frame. This cable should be such that the proximity switch can be unplugged and replaced by a push button for situations where it is more appropriate to walk.

5. Soil Thermometer

It is necessary to adjust temperature readings for the average soil temperature. Mean soil temperature can be taken in the centre of the zone where the meter measures or at 0.30 m for the horizontal mode and 0.60 m for the vertical mode.

6. Sled

To tow the EM38 behind a garden tractor or an all terrain vehicle. This sled must be built without the use of metal. The one that we built was made out of 5 x 15 cm lumber and plywood using dowels and glue.

7. Tractor or All Terrain Vehicle

The sled has to be towed 2-3 m behind the tractor with a rope to provide some distance between the EM38 and the tractor.

8. Wheel

The proximity switch is mounted onto a bicycle wheel but it could be mounted onto one of the vehicle wheels. The danger to mounting it onto a drive wheel is that there may be slippage and as a result the distances between sampling points will vary.

9. Computer Programs

The computer programs were developed to retrieve and manipulate the EM38 data. Two of these are on the portable computer (Tandy 102) and the third is on a microcomputer. These programs were written by E. Cahane.

1) The first retrieves the data directly from the EM38.
Upon starting this program, a series of prompts requires that you estimate soil temperature, soil texture and grid size as well as starting and directional co-ordinates in the field.

Each time the direction is changed, it will be necessary to pause the program and re-enter new start and directional changes.

Any other changes such as soil temperature, texture, or grid size will require that the program be stopped and restarted with the new data.

2) The other portable computer (Tandy 102) program is used to upload data to the microcomputer. This program also sets the communications parameters in the Tandy so that they are compatible with those of the PC.

3) The second program is on the microcomputer and has three options on its main menu.

   a) It is used in combination with the second data logger (Tandy 102) program to download the data file from the data logger.

   b) Once the file has been downloaded, the grid co-ordinates EC values can be applied. At this point, changes in grid size, soil temperature, and soil texture can be made if necessary.

   c) The third part of this program can be used to merge two or more portions of a field that are being held in separate files.

   The programs are designed to apply co-ordinates to the data as it is being down loaded to the micro. This requires a knowledge of your location and your direction of travel you will be driving. This information speeds up the sorting and use of the data. It also calculates apparent EC while making adjustments for temperature and moisture and texture.

Map Preparation - A program is required for calculating and drawing the contour map. There are several mapping programs available. Some of these require a plotter to draw the map.

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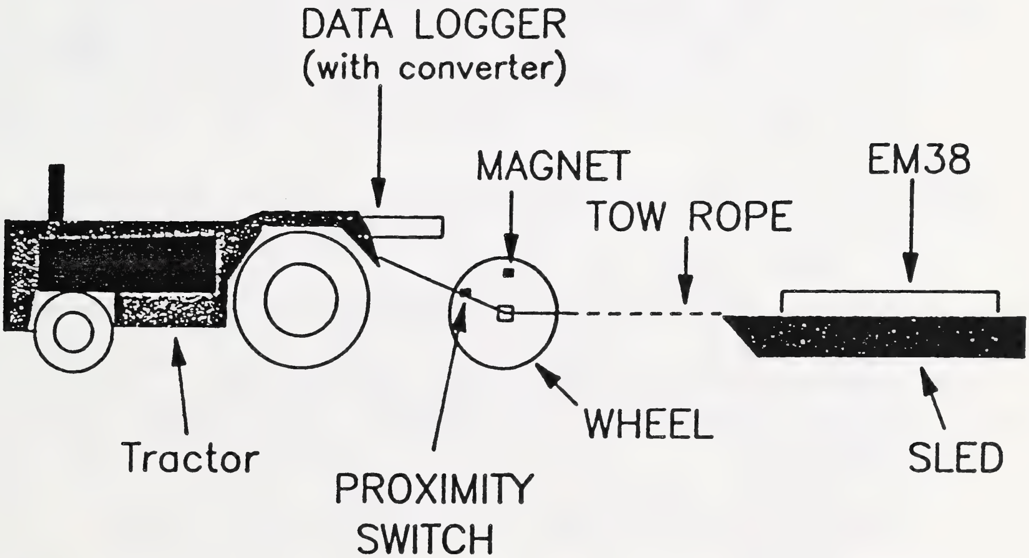
DATA LOGGER
(with converter)
MAGNET
EM38
TOW ROPE
Tractor
PROXIMITY
SWITCH
WHEEL
SLED

STAIN IDENTIFICATION OF LIVING ROOTS

R. T. Heywood[1]

Identifying living roots has been necessary in monitoring rooting depth in dryland salinity vegetative reclamation projects. This has been done by either coring or drilling to obtain soil samples and then physically examining them to see the roots. At times, soil samples have been washed to extract root tissues. In either case one of the problems encountered has been is separating "living" material from the "non-living" organic matter.

Literature (Wood, et. al. 1978) has suggested a method of staining washed out roots to assist in determining whether root material is living or dead. In this project local crops were tested to test the method and gain experience on how the method worked and any difficulties encountered.

METHOD

Root samples were obtained by the courtesy of R. Riewe, the A.I.M.S. (Alberta Irrigation Management Service) Coordinator. These were taken as part of an on-going field program monitoring rooting depth of several irrigated crops. The samples were taken by hand auger from the 0 - 15 and 15 - 30 cm depths, placed into plastic sampling bags, labelled and sealed. These samples contained all the possible types of common soil organic materials, living roots, dead roots and debris.

The root separation and staining was done the following day. The method as taken from Wood, et. al. (1978) was as follows:

1. Wash clay and silt from root samples leaving the sand fraction with the root.
2. Wash sand and roots into a flat pan (sand settles to the bottom while the roots float).
3. Decant root and organic matter onto a 75 or 100 mesh screen. Sand may have to be agitated to free roots.
4. The organic matter and roots are concentrated into a small area of the screen for staining. (Roots at this point can be stored in water and refrigerated overnight. Do not allow to dry).
5. The organic material on the screen is saturated for 3 minutes with a 1% aqueous congo red solution.
6. Rinse with cold water. Regroup organics into clump on the screen and blot dry from below with a sponge.
7. Saturate sample for 3 minutes with 95% ethanol.
8. Rinse sample with cold water.

Living roots retain a dark pink to bright red colour. Dead roots and other organic matter are unstained, light pink or brownish. Wood, et. al. (1978) also indicated that moncot roots stained less readily than dicot roots.

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The crops tested in the work were, white beans, lentils, sugar beets, fox, rape and sunflowers.

RESULTS

The root washing as expected proved time consuming and care was needed to extract representative samples. The effort increased as the clay content of the soil increased. The organic content of the samples varied as did the ratio of living and dead roots and other organic debris.

The staining method worked as indicated by literature. It must be noted that canola and lentils roots did not stain as well as the other crop roots.

CONCLUSION

The method of root staining developed by Ward, et. al. (1978) permits the separation of living roots from other organic matter and can be used to separate living from dead tissue.

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COMPARISON OF FOUR HYDROMETER METHODS FOR DETERMINATION OF PARTICLE-SIZE DISTRIBUTION IN SOILS

P.G. Karkanis and K. Au[1]

INTRODUCTION

The objectives of this study were as follows:

(1) To compare results from four commonly used hydrometer methods for determining particle-size distribution (PSD).

(2) To evaluate and describe the relationships between estimates of PSD as determined at the specific settling times used in the methods tested.

Particle-size distribution of any soil is an important measure for characterization of soils especially for irrigation and drainage purposes (Alberta Agriculture 1983). Several techniques are available for PSD measurements, the most practical of which is the hydrometer technique. Four methods tested in this study use the same hydrometer to determine the PSD in soils. This determination is based on the relationship between the settling velocity and the diameter of a spherical particle as described by Stokes' law (Stokes 1851).

MATERIALS AND METHODS

A total of 177 samples, from mineral horizons of soils, from the Brown and Dark Brown soil zones in southern Alberta were used. These soil samples represented a wide range of textural classes (Fig. 1). All soil samples were subjected to the same pretreatment procedures. A 50 g sample of the fine earth (soil with particles less than 2 mm in diameter) was soaked overnight in a solution containing 50 g L^{-1} of sodium-hexametaphosphate to enhance dispersion. Other pretreatment procedures such as removal of carbonates, soluble salts, organic matter or iron oxides were not undertaken.

Each sample was subsequently dispersed mechanically with an

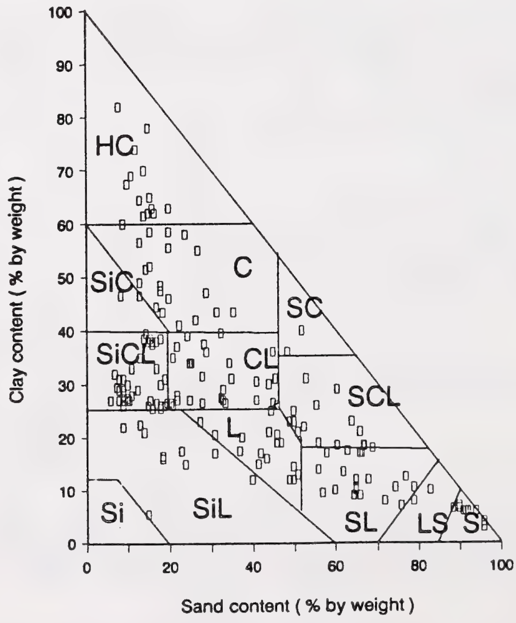

Fig. 1. Texture of soil samples used according to the Day method.

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electric mixer at 1500 rpm for 10 minutes. The mixed suspension was transferred to a special cylinder and made to a 1130 mL volume, with a ASTM No.1524 density hydrometer in suspension, by adding distilled water. The volume of suspension was rechecked after standing overnight.

The suspension in the cylinder was mixed again by turning the cylinder upside down twenty times, then placed on a level surface in a room with constant temperature of 22°C.

Density readings, using the hydrometer, were taken at sedimentation times of 30, 40, 50 and 60 s, and again at 1.5, 2, 4, 6, 8 and 24 h. Density readings were also taken, at the same time intervals, on a blank solution of sodium-hexametaphosphate to obtain a corrected reading at each settling time as follows:

$$C = R - R_L \qquad (1)$$

where C = the soil weight in grams per litre of suspension at the hydrometer reading time, R = the density of suspension and R_L = the density of the blank solution.

Sand, silt and clay contents were calculated according to settling times used by Bouyoucos (1962), Day (1965), U.S.D.I. (1982) and Gee and Bauder (1986). A comparison between results of the four methods was made, based on the hypothesis that the relationship between any two methods was linear and had a slope of one. Quadratic regression analyses were used to examine the relationship between methods, when nonlinear relationships were detected.

RESULTS AND DISCUSSION

The sand fraction, 2.0 - 0.05 mm in diameter, settled from the soil suspension in 40 to 50 s (Table 1). A predicted time is 47 s, as extrapolated from Table 1. Gee and Bauder (1979) found that differences

Table 1. Mean diameter of soil particles at different settling times, as calculated using Stokes' Law

Time	Diameter, micron.	Standard deviation	Minimum	Maximum
30 s	62.00	4.15	57.77	73.74
40 s	54.07	3.74	50.36	64.26
50 s	48.59	3.43	45.04	57.48
60 s	44.51	3.18	41.12	52.47
1.5 h	5.01	0.29	4.33	5.51
2 h	4.36	0.25	3.75	4.77
4 h	3.10	0.16	2.67	3.38
6 h	2.54	0.13	2.18	2.76
7 h	2.36	0.12	2.02	2.55
8 h	2.21	0.11	1.89	2.39
24 h	1.30	0.06	1.09	1.38

between sieve analysis and 40 s hydrometer measurements often exceeded 5% by weight. Yet recently Bohn and Gebhardt (1989) concluded that hydrometer readings anywhere between 30 and 60 s should reasonably estimate the sand content. A strong linear relationship was observed between any two of the methods, nevertheless, statistically significant differences in the slope or y-intercept values were noted. These relationships were illustrated in equations (Table 2) for sand content.

Table 2. Comparison of sand content measured by four hydrometer methods

Method	Regression equations	SE of intercept	SE of 1st deg. coefficient	R^2
Gee & Bauder vs Bouyoucos Gee & Bauder vs U.S.D.I.	$Y_2 = 0.666 + 0.995\ (Y_1)$	0.081†	0.002*	0.999
Day vs Bouyoucos Day vs U.S.D.I.	$Y_2 = -0.184 + 1.039\ (Y_1)$	0.174	0.004*	0.997
Day vs Gee & Bauder	$Y_2 = -0.870 + 1.044\ (Y_1)$	0.171†	0.004*	0.997

† y-intercept significantly different from zero, $p \leq 0.05$.
* regression coefficient significantly different from one, $p \leq 0.05$.
Note: Bouyoucos and U.S.D.I. were the same.

The silt fraction, 0.05 - 0.002 mm in diameter, settled from the soil suspension sometime after 8 h (Table 1). A predicted time is 11 h, as extrapolated from Table 1. The 2 h reading, as suggested by Bouyoucos (1962) method, cannot yield a correct estimate of the less than 0.002 mm clay fraction (Table 1). This observation corroborates the same argument by Gee and Bauder (1979). In this regard Bohn and Gebhardt (1989) noted that clay estimated from 2 h readings was significantly different from an average estimate of the 6 and 12 h readings. They also noted that the numerical difference between the 6 and 12 h readings occasionally defined different textural classes. This study illustrated the relationships between each two methods in equations (Table 3) for clay content.

Table 3. Comparison of clay content measured by four hydrometer methods

Method	Regression equations	SE of intercept	SE of 1st deg. coefficient	SE of 2nd deg. coefficient	R^2
Gee & Bauder vs Bouyoucos	$Y_2 = 1.079 + 0.735\ (Y_1) + 0.001\ (Y_1)^2$	0.393 †	0.021*	0.0002#	0.992
Day vs Bouyoucos	$Y_2 = 1.362 + 0.654\ (Y_1) + 0.003\ (Y_1)^2$	0.671 †	0.035*	0.0004#	0.980
USDI vs Bouyoucos	$Y_2 = 2.177 + 0.692\ (Y_1) + 0.002\ (Y_1)^2$	0.628 †	0.033*	0.0003#	0.982
Day vs Gee & Bauder	$Y_2 = -1.818 + 1.056\ (Y_1)$	0.257 †	0.008*		0.991
USDI vs Gee & Bauder	$Y_2 = -0.845 + 1.035\ (Y_1)$	0.219 †	0.007*		0.993
USDI vs Day	$Y_2 = 1.004 + 0.977\ (Y_1)$	0.125 †	0.004*		0.998

† y-intercept significantly different from zero, $p \leq 0.05$.
* 1° coefficient significantly different from one, $p \leq 0.05$.
\# 2° coefficient significantly different from zero, $p \leq 0.05$.

CONCLUSIONS

This study revealed statistically significant differences in estimates for sand and clay content, between any two of the four hydrometer methods evaluated. Although the Bouyoucos (1962) method is more practical and less time consuming than any other method, it yields a significantly higher clay content than any of the other three hydrometer methods. It is therefore recommended that the results obtained for the measure of the particle-size using the Bouyoucos (1962) method be converted using the equations presented in this study to one of the other three methods. These other methods are more theoretically correct than the Bouyoucos method.

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